PRELIMINARY REPORT SUBJECT TO REVISION

Sediment and Habitat Monitoring and Evaluation Program: Gunnison River, Green River, and Colorado River, WY 2004-2008

March 4, 2005
Revisions 12/31/2005

Sediment Sampling Workgroup:
Sediment Retrospective Progress Report

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Background

The underlying geomorphic processes relevant to the formation and maintenance of backwater habitats are relatively poorly understood, particularly the effects of peak-flow magnitude and duration; sediment deposition and erosion; base-flow magnitude and variability; seasonality and monsoonal rain-events, and antecedent conditions on habitat availability and conditions. Knowledge of sediment-transport dynamics in river reaches is critical to understanding the effects of flow regimes on endangered fish habitats.

Based upon a report entitled "Recommended Priorities for Geomorphology Research in Endangered Fish Habitats of the Upper Colorado River Basin" (LaGory et.al 2003), the Colorado River Recovery Implementation Program (RIP) requested proposals to conduct the sediment monitoring element of a Connected Backwaters Project, which also includes a physical habitat monitoring element involving topographic measurements of selected backwaters and adjacent exposed sandbars in each of six river reaches. After review by the geomorphology peer review panel and the RIP Biology Committee, this physical habitat-monitoring element of the project was deferred. However, installing and operating sediment samplers in conjunction with existing streamflow gages were determined to be important to supplement and expand existing understanding of sediment transport in critical habitat.

Beginning in 1998 the Recovery Program and USGS began a 5-year program of sediment data collection for the Yampa and Green Rivers (Elliot and Anders, 2004). Included in Elliot and Anders are sediment-transport equations, including equations for suspended load, bedload, total-sediment load by year, and total-sediment load by hydrograph season. For example, 40 suspended-sediment and 40 bedload measurements were made at the Green River near Jensen, Utah, at discharges ranging from 965 ft^3/s to 22,000 ft^3/s. These data included 18 measurements during the rising-limb hydrograph season and 18 measurements during the recessional- or falling-limb hydrograph season.

While periodic sediment-transport data have been collected and sediment-transport equations adequate for sediment-budget estimation have been derived for the Green River near Jensen (Elliott and Anders, 2004) no daily-sediment data have been collected. Collection of daily sediment records and associated suspended-sediment size analysis can be used to provide the basis for comparison of sediment loads computed using daily samples and sediment loads computed using the sediment-transport equations of Elliott and Anders (2004). Their sediment-transport equations are based on periodic sediment data and represent average sediment-transport conditions in a river. The average condition defined by the equations may not adequately represent episodic sediment transport and sediment concentrations that occur before or after the snowmelt hydrograph. Sediment transport characteristics in the Green River during periods of early snowmelt runoff and during rainfall runoff are usually not well defined by the average condition represented by the sediment-transport equations. The collection of daily sediment records and analysis of the distinction between sediment records computed using the two methods would be an important guide in determining sediment data collection needed to support instream habitat considerations. In addition, collection of daily suspended-sediment data and the associated periodic sediment samples, will be useful to improve existing sediment equations by supplementing existing periodic-sampling data.

Based upon a review of existing Gunnison River data sources by Pitlick and others (1999), sediment data comparable to that available for the Green River at Jensen are not available for the Gunnison River near Grand Junction (hereinafter referred to as the Whitewater station). The sediment data available for the Whitewater station are limited to periodic suspended-sediment concentrations collected between 1959 and 1999. A limited amount of sediment-size data, mostly percent of sample coarser or finer than 0.0625 millimeters, is available for this site. Therefore the development of sediment-transport equations similar to those developed for the Green River near Jensen would be limited to suspended-sediment concentration and perhaps percent of sample coarser or finer than 0.0625 millimeters. Similar to the Green River near Jensen, the collection of daily sediment records and the development of sediment-transport equations will allow for analysis of the differences between sediment records computed using each method and would be an important guide in determining sediment data collection needed to support instream habitat considerations. The Green River near Jensen represents sand-sized bed sediment and the Whitewater station represents mostly cobble-sized bed sediment. No bedload samples have been colleted at the Whitewater station. Bedload discharge will, in lieu of the collection of bedload samples, be estimated for the Whitewater station using published empirical sediment-transport equations (Einstein, 1950).

Based upon discussion with the Biology Committee, Argonne National Laboratory, and other interested individuals, the USGS was requested to submit a proposal to implement sediment sampling at two locations believed to be important to support future habitat monitoring work and to address key uncertainties in existing flow recommendations for the Green and Gunnison Rivers. The two locations are 09152500 Whitewater station (0.5 miles south of the town of Whitewater, Colorado on the Gunnison River) and 09161000 Green River near Jensen, Utah.

Project goals and objectives

Goals

The goal of the project is to characterize sediment transport at main stem sites of the Colorado, Gunnison, and Green Rivers to support the evaluation of the role of streamflow and sediment transport on the formation and maintenance of backwater habitats and spawning bars, specifically as they relate to RIP recovery efforts for the endangered fishes.

Objectives

1. To provide information, similar to Elliott and Anders (2004), for use in evaluating the magnitude, timing, and size distribution of sediment transported in the Gunnison, Green, and Colorado River systems, as it relates to future evaluations of streamflow recommendations for the Aspinall Storage Unit and Flaming Gorge Reservoir related to habitat considerations for the endangered fishes.

2. To compare two methods of sediment monitoring to determine which is best suited to support habitat monitoring and assessment needs.

Project approaches

Approach to objective 1

A retrospective analysis of historical sediment data was done to determine the availability of historic sediment data for key sites on select reaches of the Colorado, Gunnison, and Green Rivers (fig. 1). The historical sediment data will also be used to develop sediment-transport equations, evaluate trends in sediment transport, and evaluate how variations in annual hydrographs affect sediment transport.

Sediment transport in the study reaches will also be evaluated by collecting and analyzing data to compute sediment load, including suspended-sediment loads computed using daily samples and loads estimated using sediment-transport equations. Water-surface slope and bed-material samples will be collected at two sites to support bedload calculations using published sediment-transport equations. These data will be collected at the Gunnison River near Grand Junction, Colorado (Whitewater station) and the Green River near Jensen, Utah (Jensen station). These sites are representative of the range in habitat conditions found in other habitat monitoring reaches (primarily cobble bottom in the Gunnison River near Grand Junction; and a sand cobble mixture, primarily sand, found in the Green River near Jensen).

The observed relation between streamflow and sediment transport (magnitude, timing, and size distribution) related to the morphometric and bed-material characteristics of the Gunnison, Green, and Colorado Rivers will provide information useful to evaluate streamflow recommendations for the Aspinall Storage Unit and Flaming Gorge Reservoir.

Approach to objective 2

A comparison of the sediment-load estimates computed from daily-sediment data, sediment-transport equations, and empirical bedload-transport equations will be completed to aid in the assessment of what methods of sediment monitoring are best suited to support habitat monitoring and assessment.

Retrospective progress summary

Sediment data availability and spatial extent of data retrieval

A retrospective analysis of historical sediment data began with the retrieval from multiple sources including the BOR, EPA, and USGS. A screening of the data was done to identify main-stem sites. The spatial extent of the data requested from the BOR was based on select segments of the main-stems of the Gunnison, Green, and Colorado Rivers, as shown in figure 1. Data requests to the EPA included two sources: Legacy and Modern STORET. The spatial extent for the data requested from Legacy STORET was based on county boundaries (fig. 2), and the data requested from Modern STORET was based on 8-digit HUC boundaries (fig. 3). The spatial extent for the USGS data was based on 8-digit HUC boundaries (fig. 3). The spatial extent of each data set was further refined to exclude sites outside a 1.0 mile buffer of the study reaches, the remaining sites were examined and a list of main-stem sites was compiled.

Sediment data collection and analytical bias

The applicability of the data retrieved, for use in the retrospective analysis, differed between agencies dependent on the method of collection and analyses. Isokinetic, depth-and-width-integrated samples analyzed for Suspended Sediment Concentration (SSC) are best suited for the purposes of the retrospective analysis. To search for applicable data collected by the Bureau of Reclamation (BOR) Coll Stanton of Grand Junction, Colorado, was contacted; no applicable main-stem sediment data was reported. No applicable main-stem sediment data was found for use in creating sediment-transport curves from either of the EPA STORET data bases. EPA Modern STORET did contain 28 main-stem sites with Total Suspended Solids (TSS) data with greater than 20 samples per site (fig. 4). However, without corresponding SSC data the TSS data points were not suited for use in sediment-transport equation generation due to the inherent analysis bias and discontinuity between analyses practices (USGS Office of Surface Water Memo 01.03). Seven sites were found with sufficient USGS data to proceed with the retrospective analysis (fig. 5). Difference in the sampling equipment used by the USGS during the collection period at these sites, specifically between the D-74 and D-77 samplers, was also explored and the difference between the two was statistical tested to determine any affect in possible time-trends. The sites meeting both collection and analyses criteria outlined previously, were further refined based on the affects related to the completion of water-storage projects (hereinafter referred to as dams) in the basins.

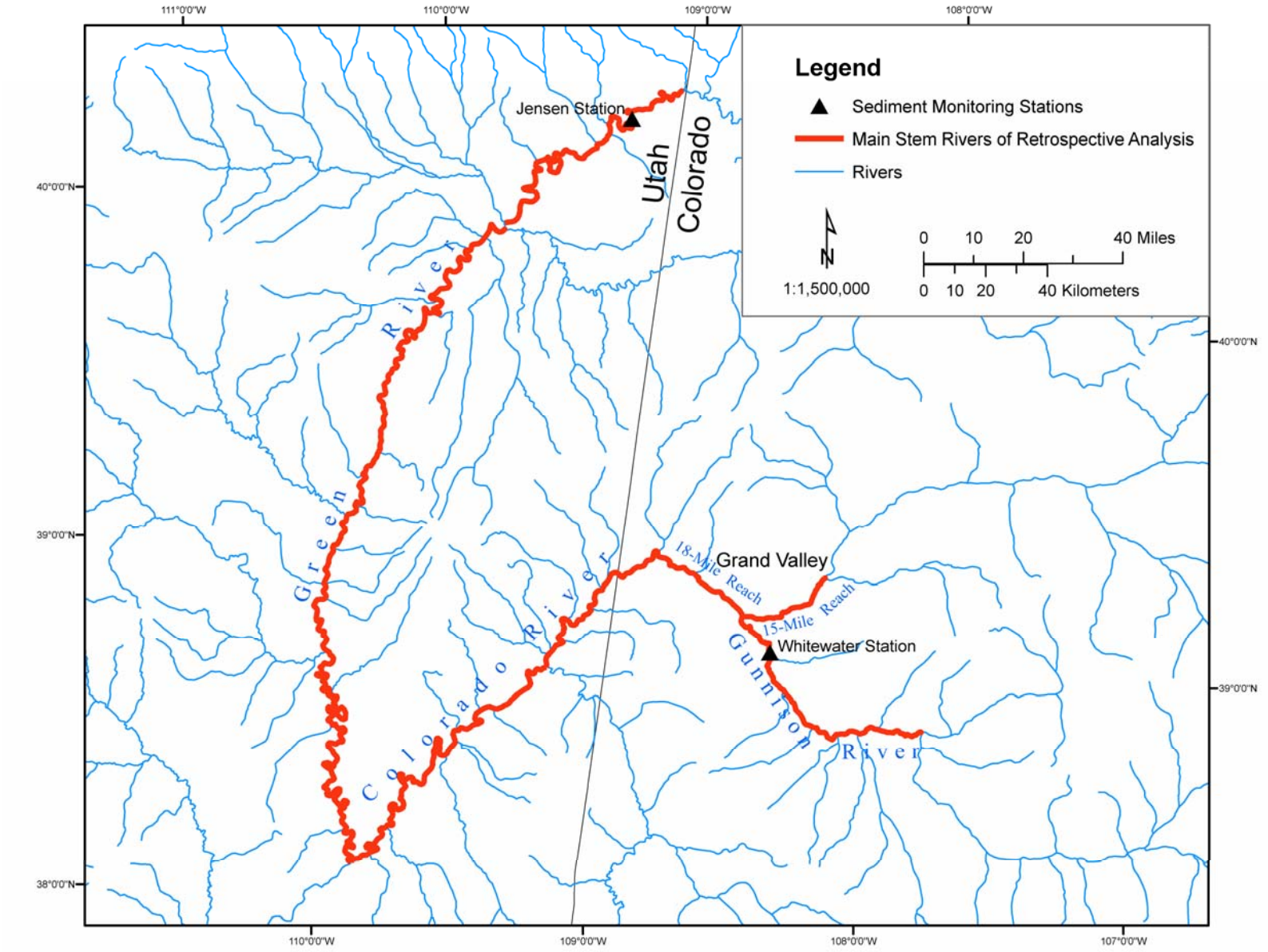

Figure 1. Location of study area and USGS sediment monitoring stations 09152500, Gunnison R. near Grand Junction, CO (Whitewater station); and 09261000, Green R. near Jensen, UT (Jensen station).

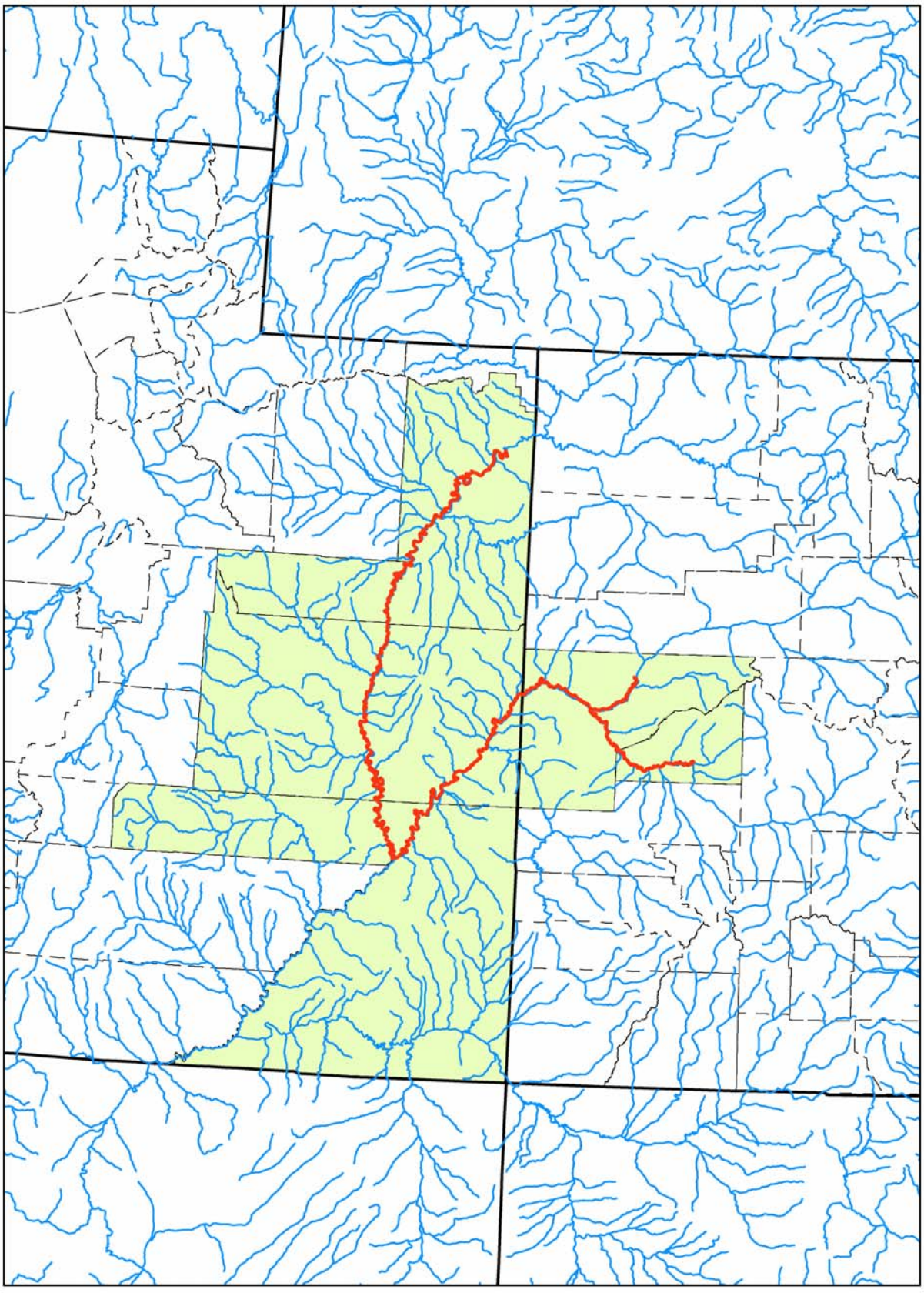

Figure 2. Location of study area and spatial extent for the data requested from Legacy STORET.

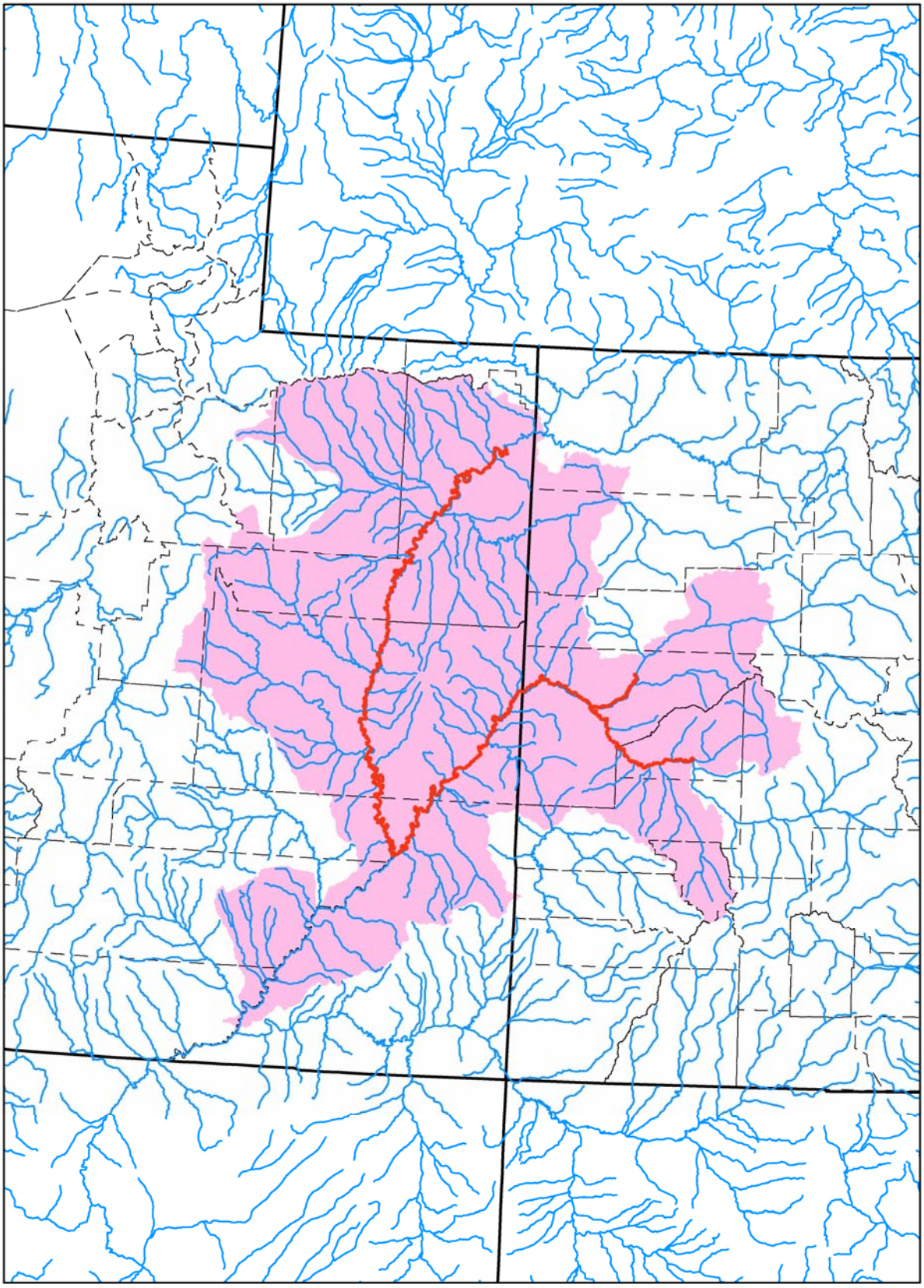

Figure 3. Location of study area and spatial extent for the data requested from Modern STORET and USGS NWIS.

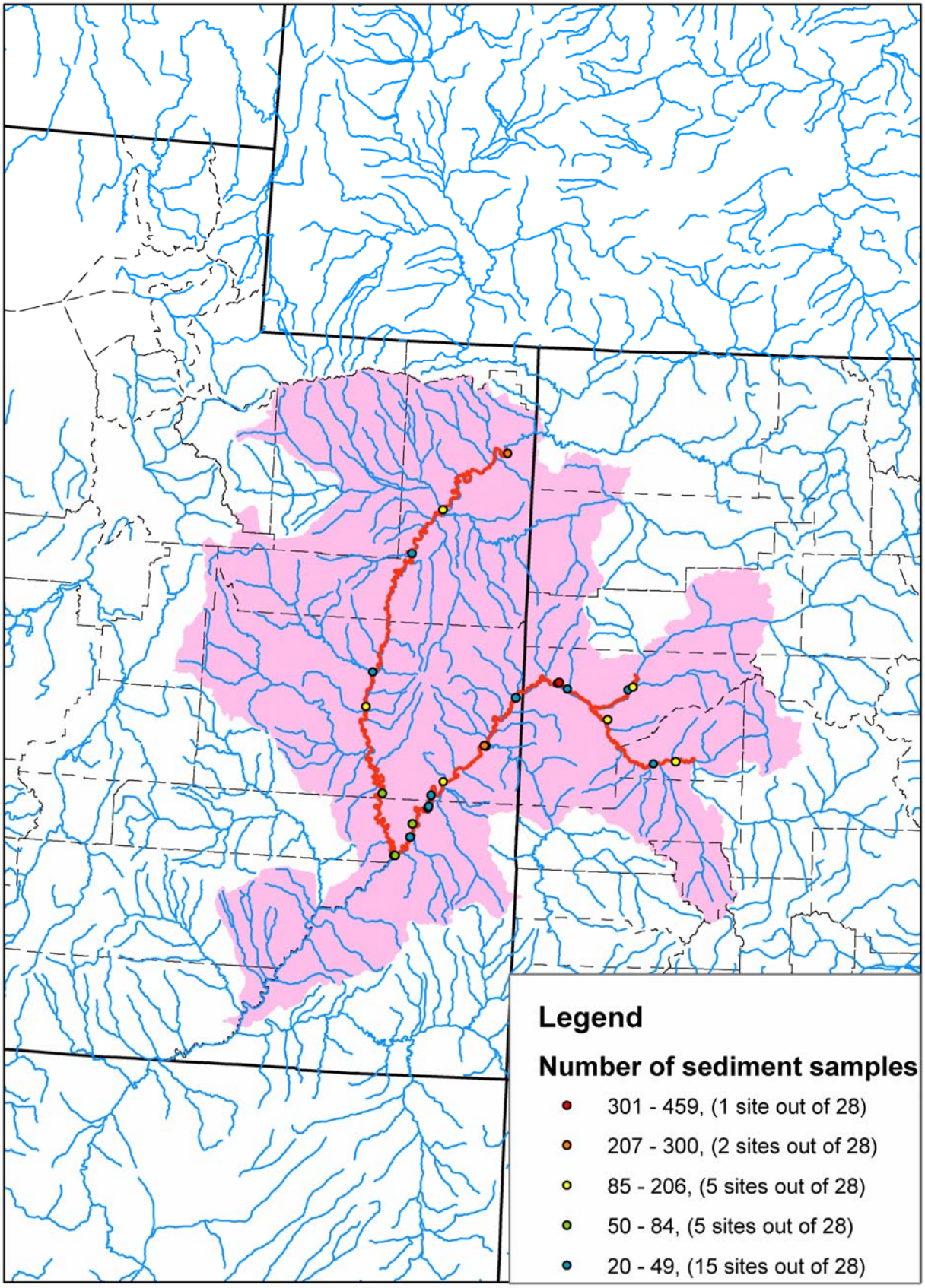

Figure 4. Location of 28 main-stem sites from Modern STORET data retrieval, with more than 20 samples of Total Suspended Solids.

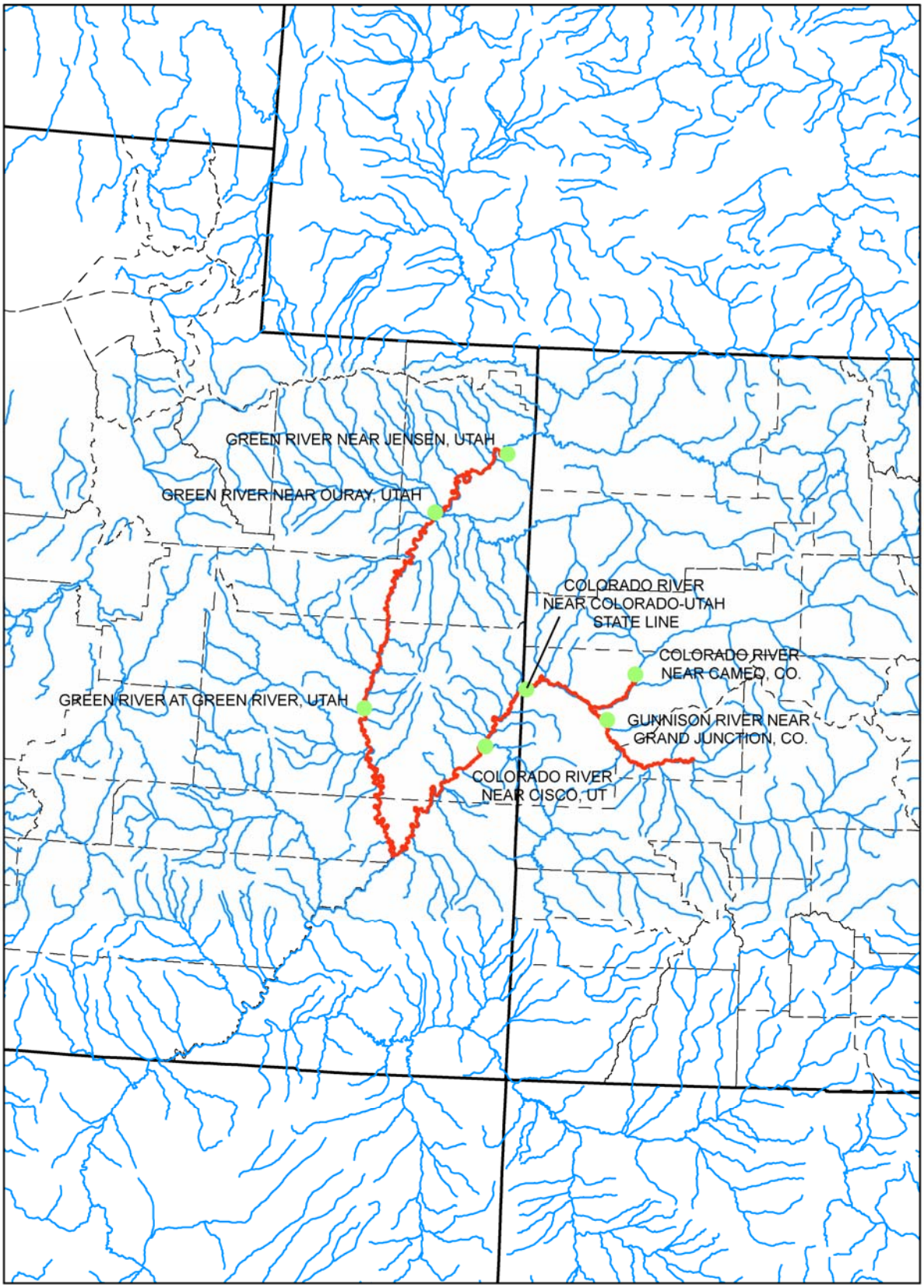

Figure 5. Location of 7 main-stem sites from USGS data retrieval with more than 20 samples of Suspended Sediment Concentration.

Dam completions and streamflow distribution

Dam completions upstream of a sediment site can affect sediment transport through sediment and streamflow retention. Sediment retention can remove sediment from the system or alter the size distribution of the sediment released from the reservoir. Streamflow retention and corresponding augmentations can alter the sediment-streamflow relation. In order to separate out time periods where dam completions affect streamflow and sediment transport, a set of tables of dam completions upstream of each sediment site was created (tables 1 and 2).

A series of tests, in conjunction with an assessment of dam location and size, were done to qualitatively ascertain if and when a significant alteration occurred. Statistical analysis of step trends, monotonic trends, and streamflow distribution analysis were employed. The dams that appear to have significantly altered the streamflow from pre-construction conditions to current conditions are summarized in table 3 for each site. The period of record and number of sediment samples available for Green R. near Ouray, UT were insufficient to generate sediment-transport equations; therefore, this site was removed from the sediment-transportation analyses.

Preliminary sediment-transport equations

Preliminary sediment-transport equations were generated for the remaining sites for use during the period of record shown in table 3. Multiple-linear regression was used for the sediment-transport equations. Step-wise regression techniques and an assessment of the statistical significance of each independent variable was made at the <0.05 level for inclusion in the transport equations. Three transport equations were generated for each site to predict total suspended-sediment load, the sand fraction of the suspended-sediment load (particles diameter than 0.0625 mm), and the silt and clay fraction of the suspended-sediment load (particle diameter less than 0.0625 mm). Additional, but less abundant, particle-size data exists for select sites and may be used to generate other transport equations to be presented in the final project report.

The variables used in the generation of the sediment-transport equations included timing variables and hydraulic variables. Timing variables include variables used to account for seasonality such as date, sine-cosine pairs of the Julian date, and monsoon season. Hydraulic variables include natural log transformed streamflow, and rising and falling limbs of the hydrograph. Preliminary results for the transport equations are presented in table 4 and in Appendix 1.

Flow-duration curves were plotted with the streamflow for the refined sediment samples to depict the coverage and range of streamflow each sediment-transport equation is based on. The coverage and range is adequate for all sites for low to high streamflow ranges. Extreme streamflow, streamflow exceeded less than 5 percent on the time, have poorer coverage for most sites. Coverage is sparser for the Green R. near Jensen, UT and Green R. at Green River, UT. The flow-duration curves and refined sample distribution plots for each site are included in Appendix 2.

Table 1. List of dams and corresponding completion dates upstream of Colorado NWIS sediment sites in the study area.

Site ID	Site name	Dam completion	Period of record by water year	
			Sediment-samples	Streamflow record
09095500	Colorado R. near Cameo, CO	Meadow Creek Reservoir, 1975 Ruedi Reservoir, 1968 Rifle Gap Reservoir, 1967 Homestake Reservoir, 1964 Dillon Reservoir, 1963 Williams Fork Reservoir, 1959 Willow Creek Reservoir, 1953 Granby Reservoir, 1950 Shadow Mountain Reservoir, 1947 Green Mountain Reservoir, 1943	1983-1998	1934-present
09152500	Gunnison R. near Grand Junction, CO	Ridgeway Reservoir, 1987 Juniata Reservoir, 1979 Silver Jack Reservoir, 1971 Aspinall Storage Unit, 1967 Paonia Reservoir, 1962 Crawford Reservoir, 1962 Gould Reservoir, 1954 Overland Reservoir #1, 1951 Fruitgrowers Reservoir, 1939 Taylor Park Reservoir, 1937	1960-1965, 1976-1999	1917-present
09163500	Colorado R. near Colorado-Utah state line	Ridgeway Reservoir, 1987 Juniata Reservoir, 1979 Jerry Creek #2 Reservoir, 1977 Meadow Creek Reservoir, 1975 Silver Jack Reservoir, 1971 Ruedi Reservoir, 1968 Aspinall Storage Unit, 1967 Rifle Gap Reservoir, 1967 Homestake Reservoir, 1964 Dillon Reservoir, 1963 Paonia Reservoir, 1962 Crawford Reservoir, 1962 Bonham Reservoir, 1962 Williams Fork Reservoir, 1959 Vega Reservoir, 1959 Gould Reservoir, 1954 Willow Creek Reservoir, 1953 Overland Reservoir #1, 1951 Granby Reservoir, 1950 Shadow Mountain Reservoir, 1947 Green Mountain Reservoir, 1943 Fruitgrowers Reservoir, 1939 Taylor Park Reservoir, 1937	1976-present	1952-present

Table 2. List of dams and corresponding completion dates upstream of Utah NWIS sediment sites in the study area.

Site ID	Site name	Dam completion	Period of record by water year	
			Sediment-samples	Streamflow record
09180500	Colorado R. near Cisco, UT	Ridgeway Reservoir, 1987 McPhee Reservoir, 1984 Juniata Reservoir, 1979 Miramonte Reservoir, 1978 Jerry Creek #2 Reservoir, 1977 Meadow Creek Reservoir, 1975 Silver Jack Reservoir, 1971 Ruedi Reservoir, 1968 Aspinall Storage Unit, 1967 Rifle Gap Reservoir, 1967 Homestake Reservoir, 1964 Dillon Reservoir, 1963 Paonia Reservoir, 1962 Crawford Reservoir, 1962 Bonham Reservoir, 1962 Gurley Reservoir, 1961 Williams Fork Reservoir, 1959 Vega Reservoir, 1959 Gould Reservoir, 1954 Willow Creek Reservoir, 1953 Overland Reservoir #1, 1951 Granby Reservoir, 1950 Shadow Mountain Reservoir, 1947 Green Mountain Reservoir, 1943 Summit Reservoir, 1939 Fruitgrowers Reservoir, 1939 Groundhog Lake, 1938 Taylor Park Reservoir, 1937	1951-2000	1923-present
09261000	Green R. near Jensen, UT	Yamcolo Reservoir, 1980 Long Park Reservoir, 1980 Stateline Reservoir, 1979 Elk Head Reservoir, 1979 Pearl Lake, 1975 Lake Catamount, 1974 Meeks Cabin Reservoir, 1971 Steamboat Lake, 1966 Fontenelle Reservoir, 1964 Flaming Gorge Reservoir, 1964 Boulder Lake, 1964 Mc Chivvies Reservoir, 1962 Viva Naughton Reservoir, 1961 Big Sandy Reservoir, 1952	1952, 1960-89, 1996-2002	1947-present

Table 2. List of dams and corresponding completion dates upstream of Utah NWIS sediment sites in the study area. –Continued

Site ID	Site name	Dam completion	Period of record by water year	
			Sediment-samples	Streamflow record
09307000	Green R. near Ouray, UT	Upper Stillwater Reservoir, 1987 Brown's Draw Reservoir, 1981 Yamcolo Reservoir, 1980 Red Fleet Reservoir, 1980 Long Park Reservoir, 1980 Stateline Reservoir, 1979 Elk Head Reservoir, 1979 Currant Creek Reservoir, 1977 Pearl Lake, 1975 Lake Catamount, 1974 Meeks Cabin Reservoir, 1971 Starvation Reservoir, 1970 Bottle Hollow Reservoir, 1970 Pelican Lake, 1967 Steamboat Lake, 1966 Big Sand Wash Reservoir, 1965 Flaming Gorge Reservoir, 1964 Lake Avery, 1964 Fontenelle Reservoir, 1964 Boulder Lake, 1964 Mc Chivvies Reservoir, 1962 Viva Naughton Reservoir, 1961 Steinaker Reservoir, 1961 Red Creek Reservoir, 1960 Big Sandy Reservoir, 1952	1952, 1960-1966	1948-1955, 1957-1966
09315000	Green R. at Green River, UT	Upper Stillwater Reservoir, 1987 Brown's Draw Reservoir, 1981 Yamcolo Reservoir, 1980 Red Fleet Reservoir, 1980 Long Park Reservoir, 1980 Stateline Reservoir, 1979 Elk Head Reservoir, 1979 Currant Creek Reservoir, 1977 Pearl Lake, 1975 Lake Catamount, 1974 Meeks Cabin Reservoir, 1971 Starvation Reservoir, 1970 Bottle Hollow Reservoir, 1970 Pelican Lake, 1967 Steamboat Lake, 1966 Big Sand Wash Reservoir, 1965 Flaming Gorge Reservoir, 1964 Lake Avery, 1964	1951-2000	1906-present

Table 2. List of dams and corresponding completion dates upstream of Utah NWIS sediment sites in the study area. –Continued

Site ID	Site name	Dam completion	Period of record by water year	
			Sediment-samples	Streamflow record
09315000	Green R. at Green River, UT –Continued	Fontenelle Reservoir, 1964 Boulder Lake, 1964 Mc Chivvies Reservoir, 1962 Viva Naughton Reservoir, 1961 Steinaker Reservoir, 1961 Red Creek Reservoir, 1960 Big Sandy Reservoir, 1952 Fairview Tunnel, 1949 Scofield Reservoir, 1946 Sixty-seven Reservoir, 1942 Stillwater Reservoir #1, 1939 Oak Park Reservoir, 1938 Moon Lake, 1938 Midview Reservoir, 1937 Fremont Lake, 1934 Willow Lake, 1931 New Fork Lake, 1928 Strawberry Reservoir, 1912 Eden Valley Reservoir #1, 1910	1951-2000	1906-present

Table 3. Summary of NWIS sediment sites in the study area.

Site ID	Site name	Dams affecting the streamflow-distribution and duration curves	Refined period of record by water year		Number of sediment samples available to generate transport equations		
			Sediment-samples	Streamflow record	Sand	Suspended sediment concentration	Silt/clay
09095500	Colorado R. near Cameo, CO	None during period of sediment record	1983-1998	1983-present	435	529	435
09152500	Gunnison R. near Grand Junction, CO	Aspinall Storage Unit, 1967	1976-1999	1968-present	116	264	116
09163500	Colorado R. near Colorado-Utah state line	Aspinall Storage Unit, 1967	1976-present	1968-present	163	247	163
09180500	Colorado R. near Cisco, UT	Aspinall Storage Unit, 1967	1968-2000	1968-present	156	307	156
09261000	Green R. near Jensen, UT	Flaming Gorge Reservoir, 1964	1965-89, 1996-2002	1965-present	30	205	30
09307000*	Green R. near Ouray, UT*	Flaming Gorge Reservoir, 1964	1965-1966*	1965-1966*	1*	17*	1*
09315000	Green R. at Green River, UT	Flaming Gorge Reservoir, 1964	1951-2000	1965-present	159	328	159

* Period of record and number of sediment samples available insufficient to generate sediment-transport equations; site removed from sediment-transportation analyses.

Table 4. Summary of transport-equation logistics and statistical diagnostics.

Site name	Type of suspended sediment load	n	Range of streamflow estimations x 1000 in cfs	Independent variables								R2	Standard error
				Y intercept	LnQ	Rising	D74	Date	Monsoon	sine-cosine pair Julian date, year period C, D	sine-cosine pair Julian date, half-year period E,F		
Colorado R. near Cameo, CO	Total	529	1-32	X	X	X			X	X	X	0.74	0.966
Colorado R. near Cameo, CO	Sand	435	1-32	X	X					X	X	0.82	0.866
Colorado R. near Cameo, CO	Silt/Clay	435	1-32	X	X	X			X	X	X	0.69	1.05
Gunnison R. near Grand Junction, CO	Total	264	0.5-18.5	X	X	X		X		X	X	0.80	0.776
Gunnison R. near Grand Junction, CO	Sand	116	0.5-17.5	X	X							0.73	1.19
Gunnison R. near Grand Junction, CO	Silt/Clay	116	0.5-17.5	X	X	X		X		X	X	0.83	0.725
Colorado R. near Colorado-Utah state line	Total	247	1-57.5	X	X	X		X	X	X	X	0.77	0.923
Colorado R. near Colorado-Utah state line	Sand	163	1-57.5	X	X					X	X	0.69	1.25
Colorado R. near Colorado-Utah state line	Silt/Clay	163	1-57.5	X	X	X				X	X	0.67	1.01
Colorado R. near Cisco, UT	Total	307	1-54.5	X	X	X		X		X	X	0.74	1.09
Colorado R. near Cisco, UT	Sand	156	1.5-38	X	X			X		X		0.56	2.31
Colorado R. near Cisco, UT	Silt/Clay	156	1.5-38	X	X					X	X	0.69	1.04
Green R. near Jensen, UT	Total	205	1-29	X	X			X		X	X	0.72	1.00
Green R. near Jensen, UT	Sand	30	1.5-21	X	X			X		X		0.93	1.78
Green R. near Jensen, UT	Silt/Clay	30	1.5-21		X							0.97	1.47
Green R. at Green River, UT	Total	328	1.5-47	X	X			X		X	X	0.74	0.948
Green R. at Green River, UT	Sand	159	1.5-39.5	X	X							0.44	3.08
Green R. at Green River, UT	Silt/Clay	159	1.5-39.5	X	X		X			X	X	0.67	0.973

Appendix 1: Statistical diagnostics

Preliminary transport equation: Do not cite

Colorado R. near Cameo, CO – Total suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.80155AvgDay ~ C + D + E + F + LnP.00060 + Rising + Monsoon,
      data = TEqCameoData, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q     Max
 -2.009 -0.6491 -0.1486 0.5244 4.368

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)  XXXXXX   0.7974   -13.6304   0.0000
          C  XXXXXX   0.0698     8.6916   0.0000
          D  XXXXXX   0.0968     1.4237   0.1552
          E  XXXXXX   0.0717     3.4227   0.0007
          F  XXXXXX   0.0736    -6.2707   0.0000
  LnP.00060  XXXXXX   0.0994    21.6937   0.0000
     Rising  XXXXXX   0.1409     4.8376   0.0000
    Monsoon  XXXXXX   0.1385     6.9152   0.0000

Residual standard error: 0.9659 on 479 degrees of freedom
Multiple R-Squared: 0.7373
F-statistic: 192.1 on 7 and 479 degrees of freedom, the p-value is 0
1 observations deleted due to missing values
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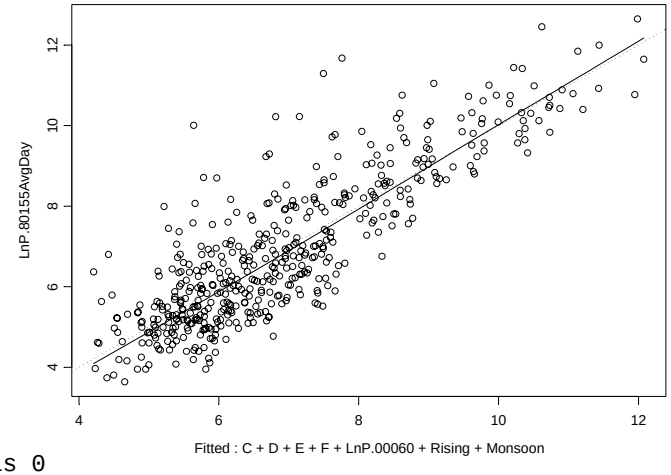

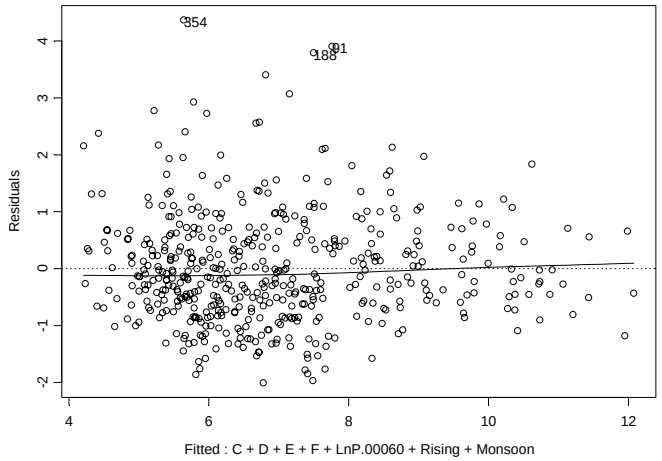

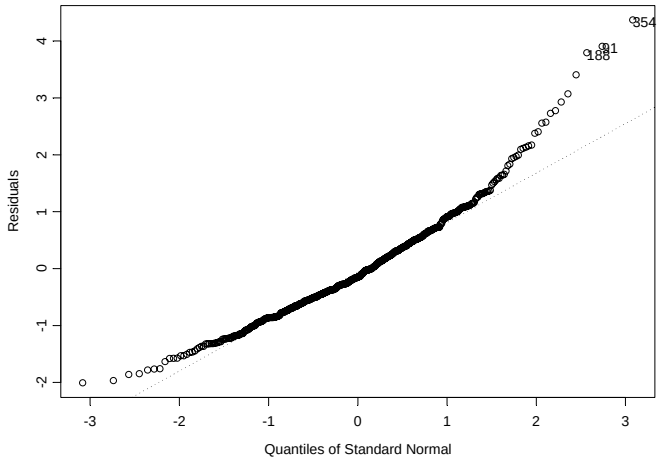

Preliminary transport equation: Do not cite

Colorado R. near Cameo, CO – Sand fraction of suspended sediment load

```
   *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayG ~ C + D + E + F + LnP.00060, data = TEqCameoData,
      na.action = na.exclude)
Residuals:
    Min      1Q   Median     3Q   Max
 -2.811 -0.5334 -0.05977 0.4743 4.091

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   0.7522   -19.5485   0.0000
          C   XXXXXX   0.0592     8.5178   0.0000
          D   XXXXXX   0.0908     0.1447   0.8850
          E   XXXXXX   0.0674    -2.4212   0.0159
          F   XXXXXX   0.0698    -5.7467   0.0000
  LnP.00060   XXXXXX   0.0935    26.1170   0.0000

Residual standard error: 0.8664 on 419 degrees of freedom
Multiple R-Squared: 0.8155
F-statistic: 370.4 on 5 and 419 degrees of freedom, the p-value is 0
63 observations deleted due to missing values
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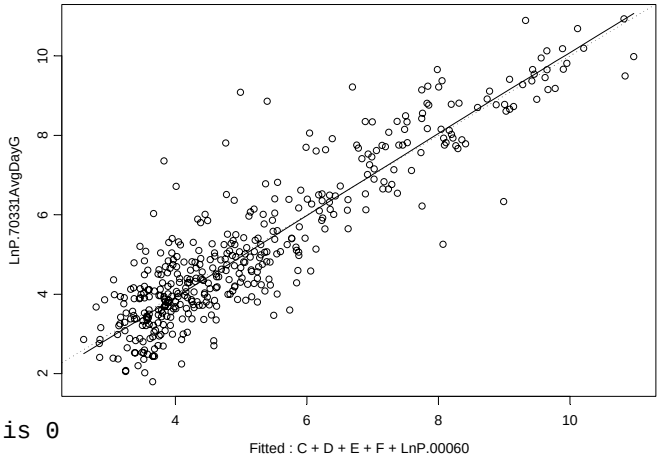
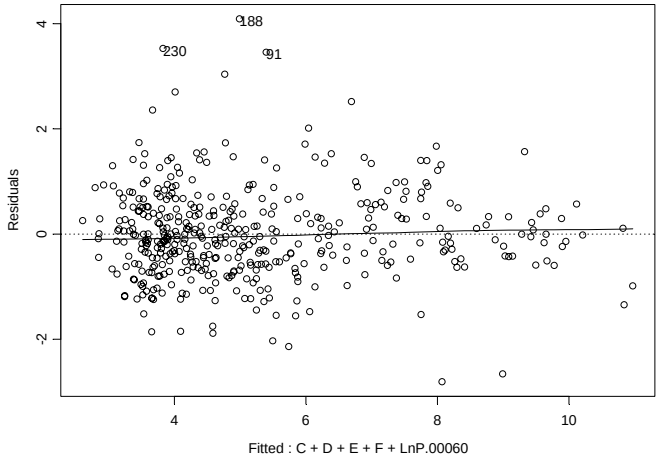
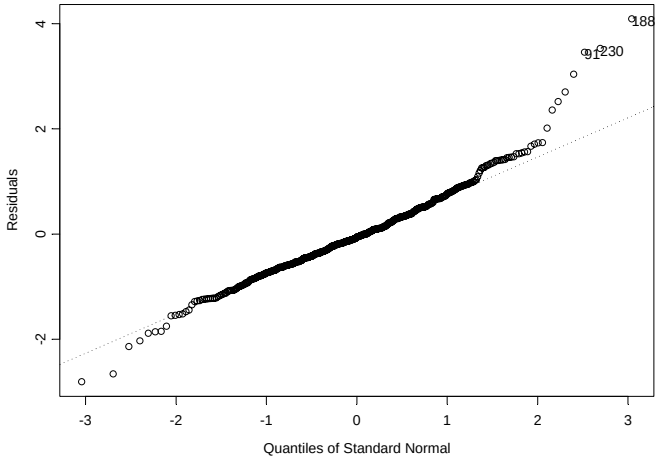


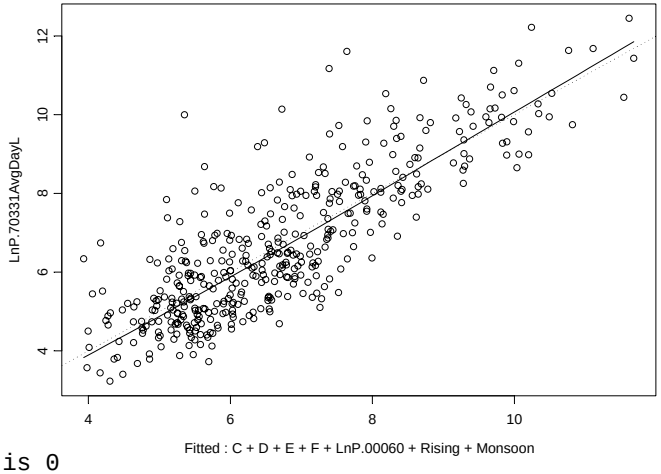


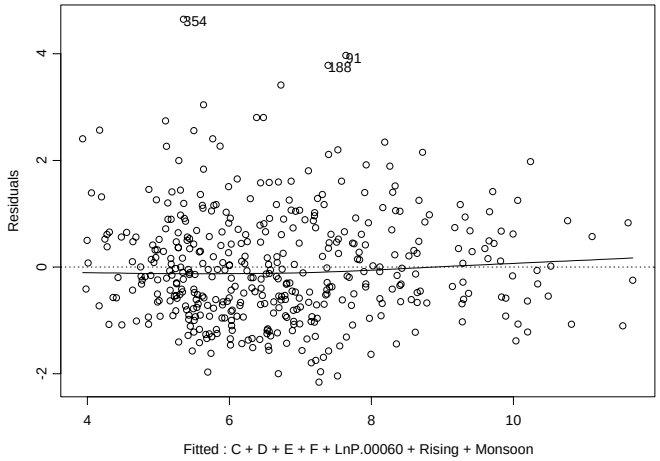


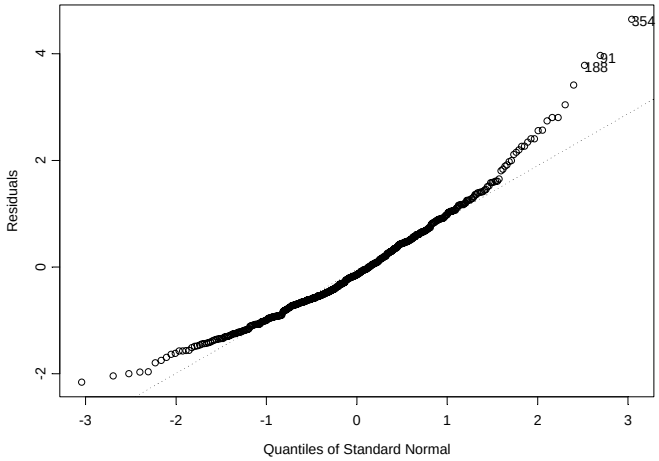
Preliminary transport equation: Do not cite

Colorado R. near Cameo, CO – Silt and clay fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayL ~ C + D + E + F + LnP.00060 + Rising + Monsoon,
      data = TEqCameoData, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q   Max
 -2.161 -0.7044 -0.1422 0.6093 4.644

Coefficients:
                Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   0.9177   -11.8272   0.0000
          C   XXXXXX   0.0839     6.5968   0.0000
          D   XXXXXX   0.1133     1.7130   0.0875
          E   XXXXXX   0.0854     3.7780   0.0002
          F   XXXXXX   0.0866    -6.3331   0.0000
  LnP.00060   XXXXXX   0.1147    18.5158   0.0000
     Rising   XXXXXX   0.1639     4.8682   0.0000
    Monsoon   XXXXXX   0.1605     6.0107   0.0000

Residual standard error: 1.049 on 417 degrees of freedom
Multiple R-Squared: 0.6896
F-statistic: 132.3 on 7 and 417 degrees of freedom, the p-value is 0
63 observations deleted due to missing values
```



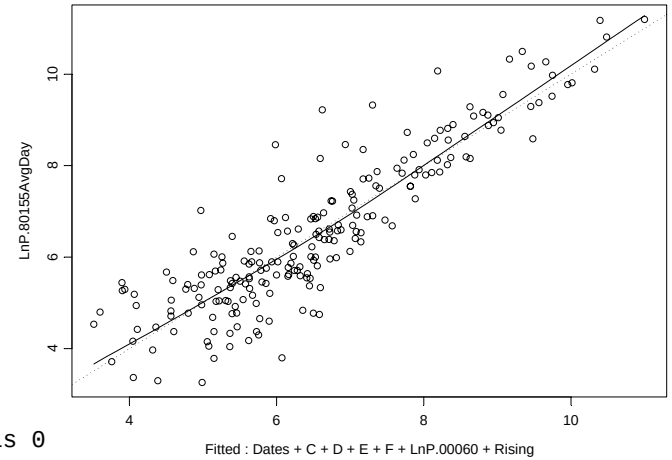


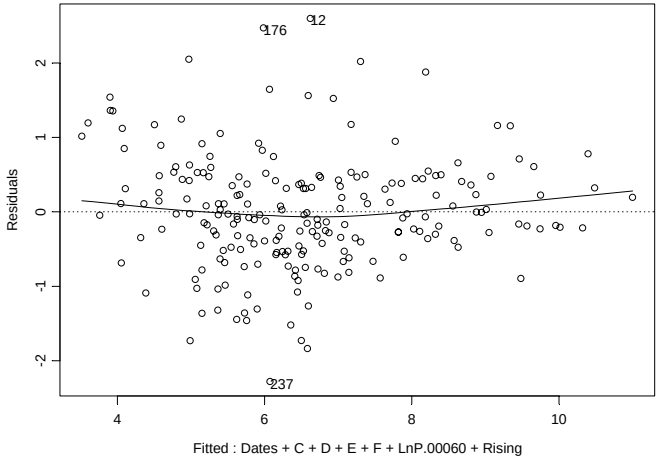


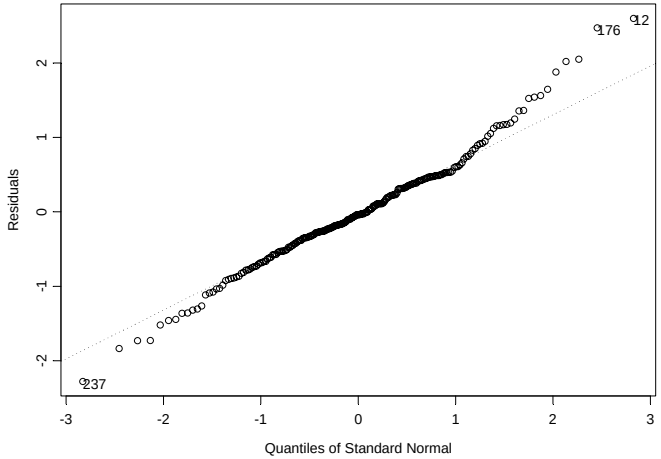
Preliminary transport equation: Do not cite

Gunnison R. near Grand Junction, CO (Whitewater) – Total fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.80155AvgDay ~ Dates + C + D + E + F + LnP.00060 + Rising,
      data = TEqWwDataPostAspinall, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q   Max
 -2.279 -0.4497 -0.0389 0.4357 2.599

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   0.6709    -7.2898   0.0000
      Dates   XXXXXX   0.0000    -4.5320   0.0000
          C   XXXXXX   0.0785     0.8924   0.3732
          D   XXXXXX   0.0801   -10.9366   0.0000
          E   XXXXXX   0.0813    -1.5294   0.1277
          F   XXXXXX   0.0820    -4.2269   0.0000
  LnP.00060   XXXXXX   0.0918    17.0933   0.0000
     Rising   XXXXXX   0.1228     5.1330   0.0000

Residual standard error: 0.776 on 205 degrees of freedom
Multiple R-Squared: 0.803
F-statistic: 119.3 on 7 and 205 degrees of freedom, the p-value is 0
42 observations deleted due to missing values
```





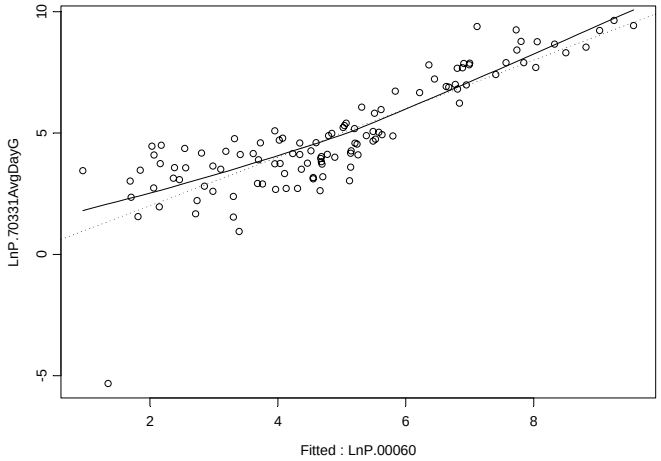


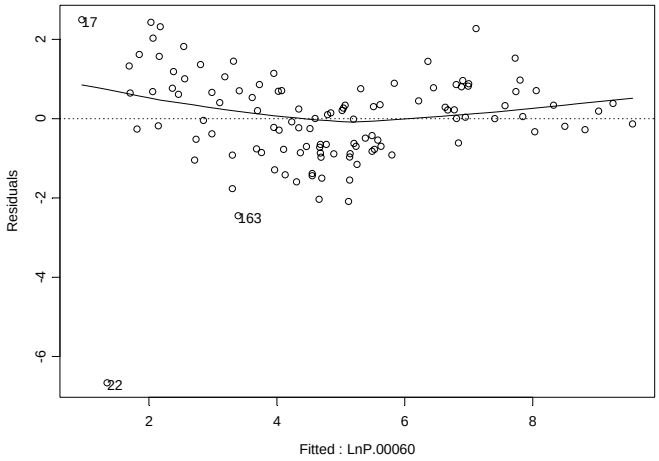
Appendix 1.4

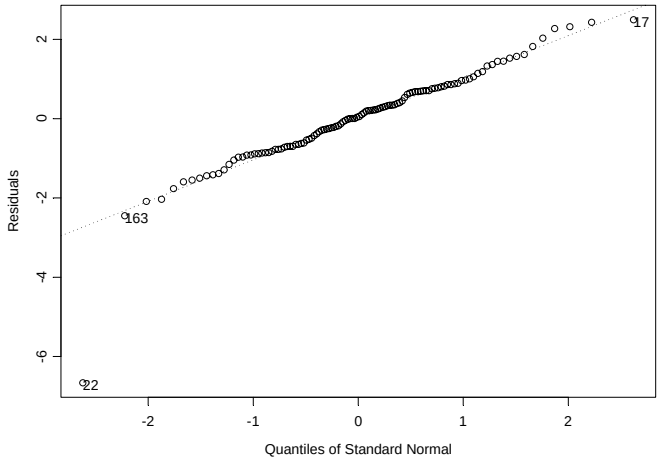
Preliminary transport equation: Do not cite

Gunnison R. near Grand Junction, CO (Whitewater) – Sand fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayG ~ LnP.00060, data = TEqWwDataPostAspinall,
      na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q   Max
 -6.666 -0.7032 0.04195 0.7068 2.493

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   1.0791   -12.7623   0.0000
  LnP.00060   XXXXXX   0.1376    17.3388   0.0000

Residual standard error: 1.19 on 112 degrees of freedom
Multiple R-Squared: 0.7286
F-statistic: 300.6 on 1 and 112 degrees of freedom, the p-value is 0
141 observations deleted due to missing values
```



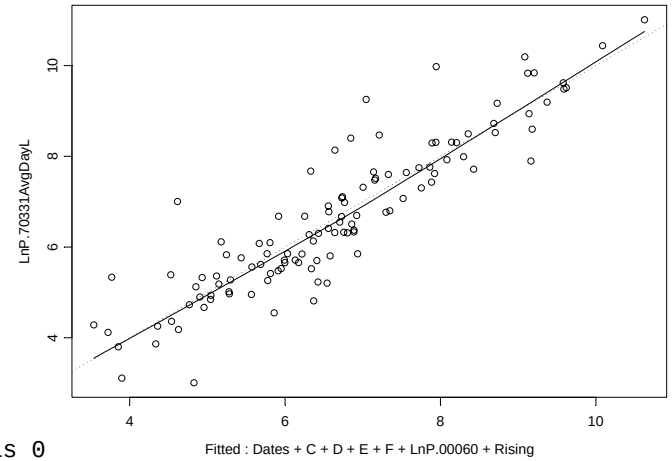


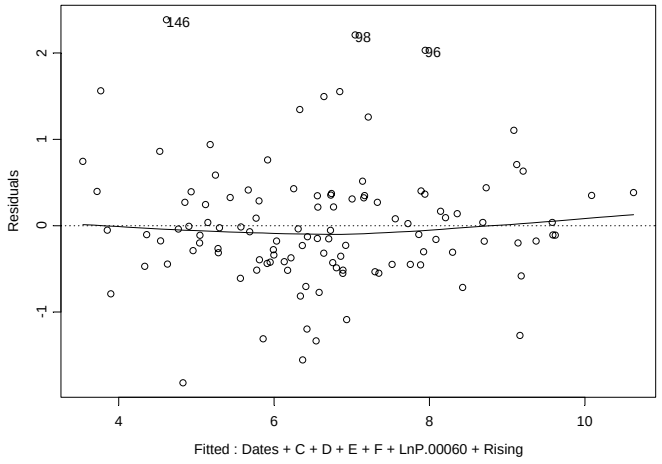


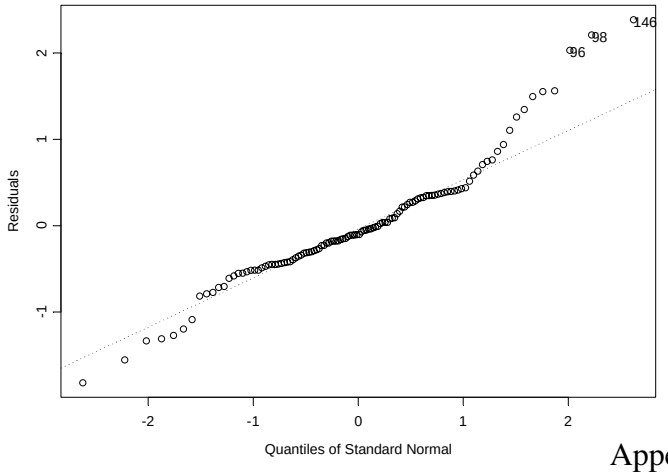
Preliminary transport equation: Do not cite

Gunnison R. near Grand Junction, CO (Whitewater) – Silt and clay fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayL ~ Dates + C + D + E + F + LnP.00060 + Rising,
      data = TEqWwDataPostAspinall, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q   Max
 -1.821 -0.4222 -0.1042 0.3465 2.385

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   0.8071    -4.9987   0.0000
      Dates   XXXXXX   0.0000    -2.9601   0.0038
          C   XXXXXX   0.1018     0.4446   0.6575
          D   XXXXXX   0.1170    -7.9562   0.0000
          E   XXXXXX   0.1071    -0.4402   0.6607
          F   XXXXXX   0.1110    -4.6216   0.0000
  LnP.00060   XXXXXX   0.1142    12.8220   0.0000
     Rising   XXXXXX   0.1563     4.2986   0.0000

Residual standard error: 0.7251 on 106 degrees of freedom
Multiple R-Squared: 0.8263
F-statistic: 72.03 on 7 and 106 degrees of freedom, the p-value is 0
141 observations deleted due to missing values
```



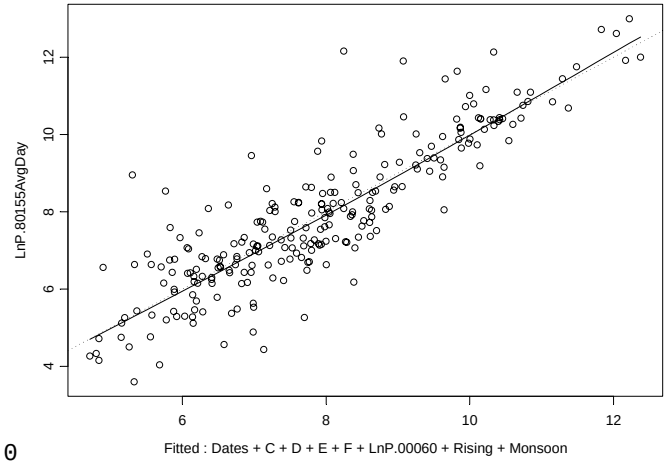


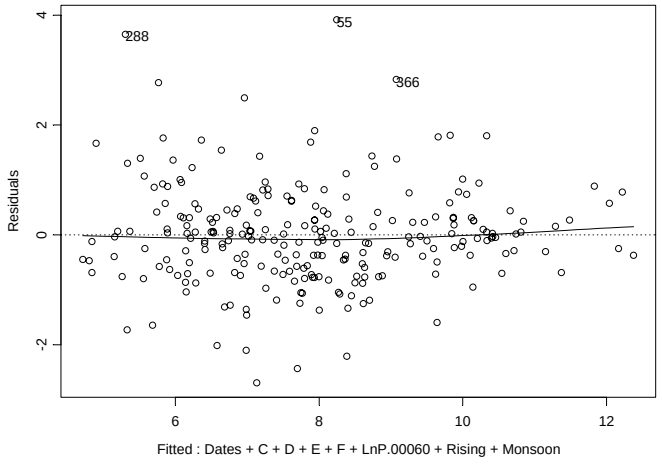


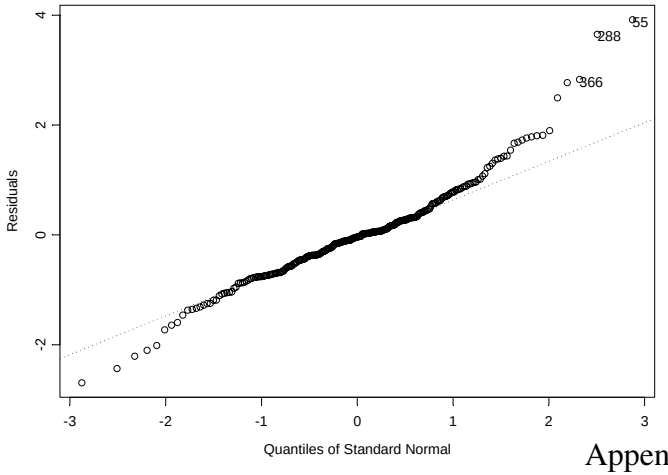
Preliminary transport equation: Do not cite

Colorado R. near Colorado-Utah State Line – Total fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.80155AvgDay ~ Dates + C + D + E + F + LnP.00060 + Rising +
      Monsoon, data = TEqStatelineData, na.action = na.exclude)
Residuals:
    Min      1Q   Median     3Q   Max
 -2.694 -0.5455 -0.03979 0.4039 3.914

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   0.9684    -4.8264   0.0000
      Dates   XXXXXX   0.0000    -4.5702   0.0000
          C   XXXXXX   0.1145     1.5623   0.1196
          D   XXXXXX   0.1021    -8.1142   0.0000
          E   XXXXXX   0.0944     0.1095   0.9129
          F   XXXXXX   0.0946    -4.1735   0.0000
  LnP.00060   XXXXXX   0.1089    13.9743   0.0000
     Rising   XXXXXX   0.1643     4.1201   0.0001
    Monsoon   XXXXXX   0.2005     3.8851   0.0001

Residual standard error: 0.923 on 238 degrees of freedom
Multiple R-Squared: 0.7717
F-statistic: 100.6 on 8 and 238 degrees of freedom, the p-value is 0
132 observations deleted due to missing values
```



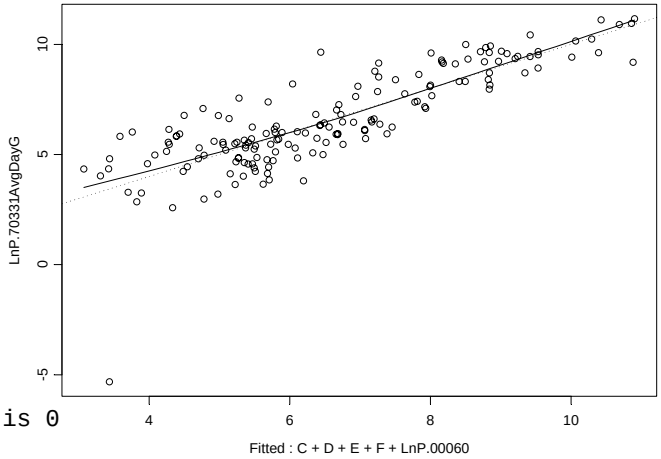


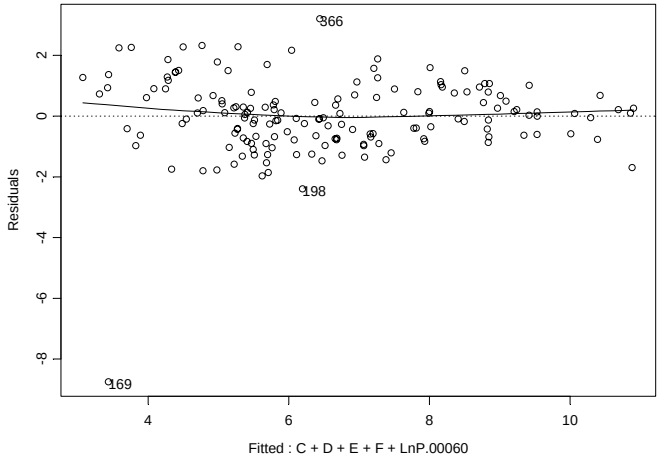


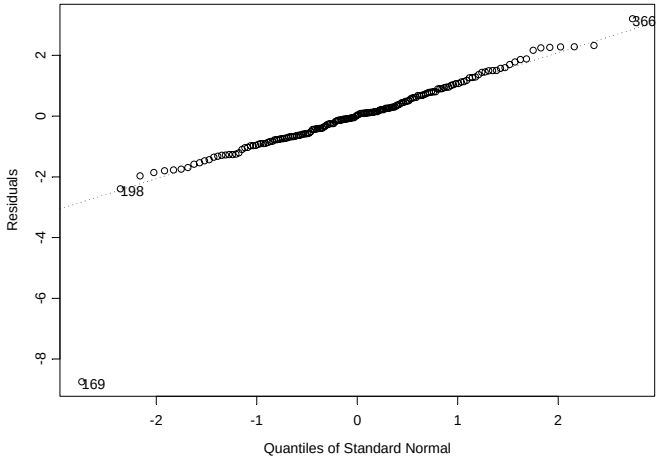
Preliminary transport equation: Do not cite

Colorado R. near Colorado-Utah State Line – Sand fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayG ~ C + D + E + F + LnP.00060, data =
      TEqStatelineData, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q   Max
 -8.753 -0.6881 0.02967 0.7103 3.205

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   1.5782    -6.4498   0.0000
          C   XXXXXX   0.1515    -0.7570   0.4502
          D   XXXXXX   0.1789    -4.3063   0.0000
          E   XXXXXX   0.1599    -3.3175   0.0011
          F   XXXXXX   0.1550    -2.1498   0.0331
  LnP.00060   XXXXXX   0.1832    10.2444   0.0000

Residual standard error: 1.252 on 157 degrees of freedom
Multiple R-Squared: 0.6929
F-statistic: 70.84 on 5 and 157 degrees of freedom, the p-value is 0
216 observations deleted due to missing values
```



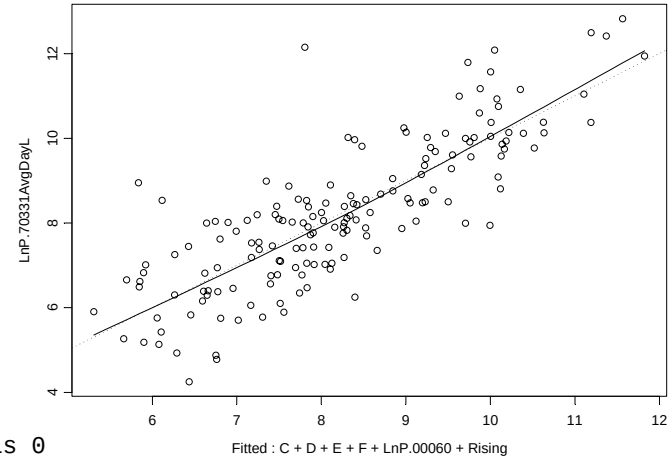


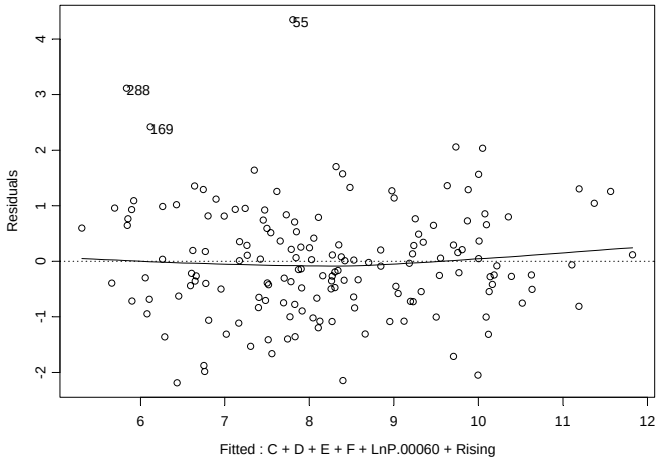


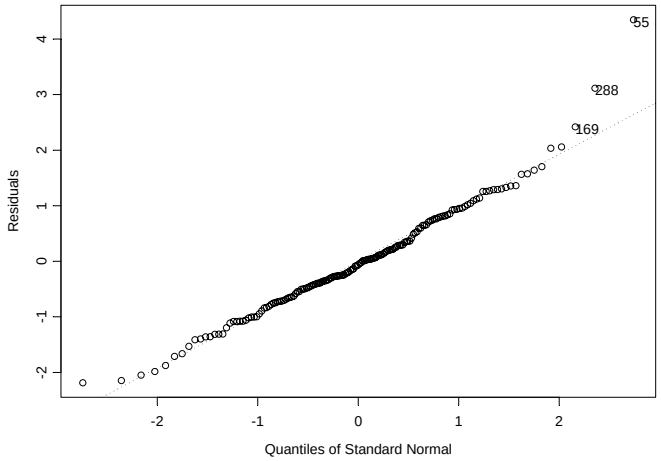
Preliminary transport equation: Do not cite

Colorado R. near Colorado-Utah State Line – Silt and clay fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayL ~ C + D + E + F + LnP.00060 + Rising, data =
      TEqStatelineData, na.action = na.exclude)
Residuals:
    Min      1Q   Median    3Q   Max
 -2.187 -0.6462 -0.06455 0.651 4.346

Coefficients:
             Value Std. Error t value Pr(>|t|)
(Intercept)  XXXXXX   1.2872    -2.8226  0.0054
          C  XXXXXX   0.1264    -1.8423  0.0673
          D  XXXXXX   0.1486    -4.2267  0.0000
          E  XXXXXX   0.1302     0.9950  0.3213
          F  XXXXXX   0.1290    -4.0344  0.0001
  LnP.00060  XXXXXX   0.1502     8.6373  0.0000
     Rising  XXXXXX   0.2083     5.5630  0.0000

Residual standard error: 1.012 on 156 degrees of freedom
Multiple R-Squared: 0.6724
F-statistic: 53.36 on 6 and 156 degrees of freedom, the p-value is 0
216 observations deleted due to missing values
```



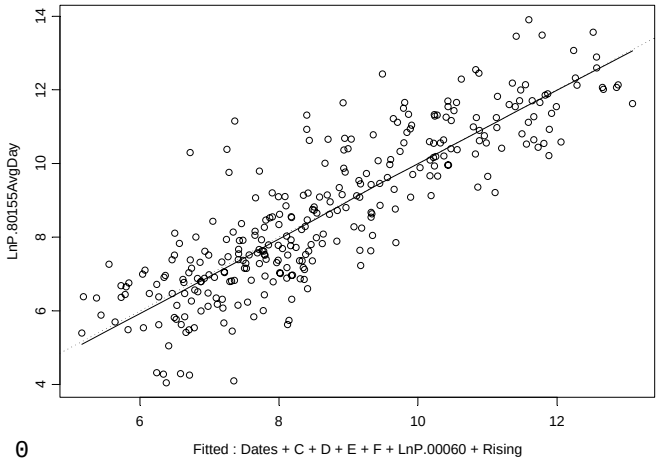


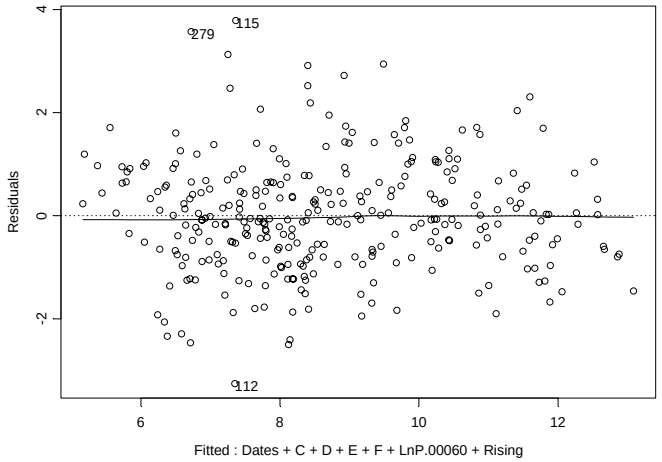


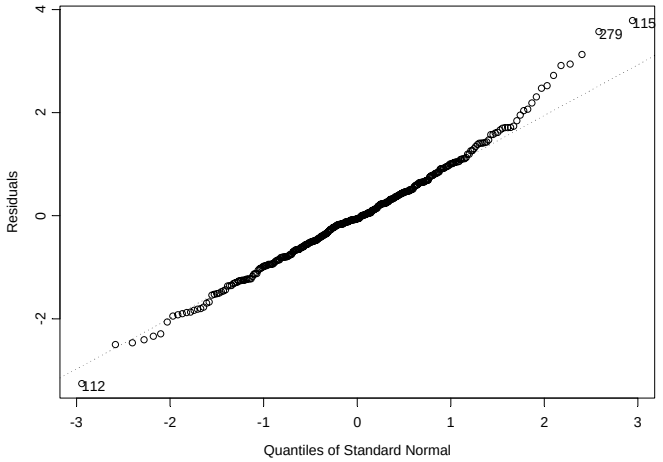
Preliminary transport equation: Do not cite

Colorado R. near Cisco, UT – Total fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.80155AvgDay ~ Dates + C + D + E + F + LnP.00060 + Rising,
      data = TEqCiscoDataRecalc80155, na.action = na.exclude)
Residuals:
    Min      1Q   Median     3Q   Max
 -3.258 -0.6845 -0.06193 0.6428 3.786

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   0.9949    -8.2708   0.0000
      Dates   XXXXXX   0.0000    -6.7009   0.0000
          C   XXXXXX   0.0934    -3.1076   0.0021
          D   XXXXXX   0.1151    -4.4849   0.0000
          E   XXXXXX   0.1000     2.3849   0.0177
          F   XXXXXX   0.0964    -6.5081   0.0000
  LnP.00060   XXXXXX   0.1148    17.3243   0.0000
     Rising   XXXXXX   0.1580     6.9738   0.0000

Residual standard error: 1.089 on 299 degrees of freedom
Multiple R-Squared: 0.7406
F-statistic: 122 on 7 and 299 degrees of freedom, the p-value is 0
125 observations deleted due to missing values
```



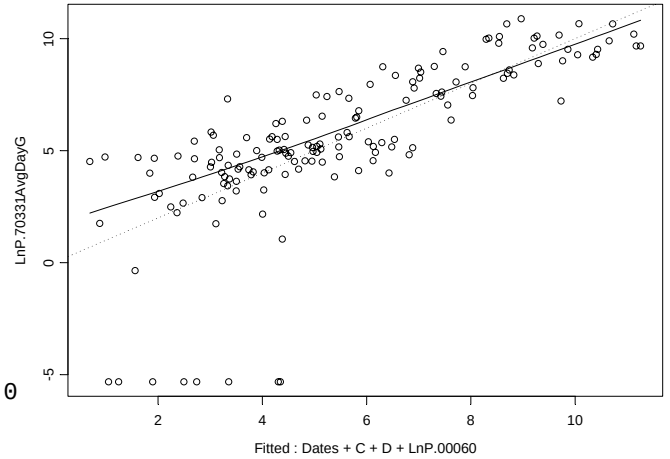


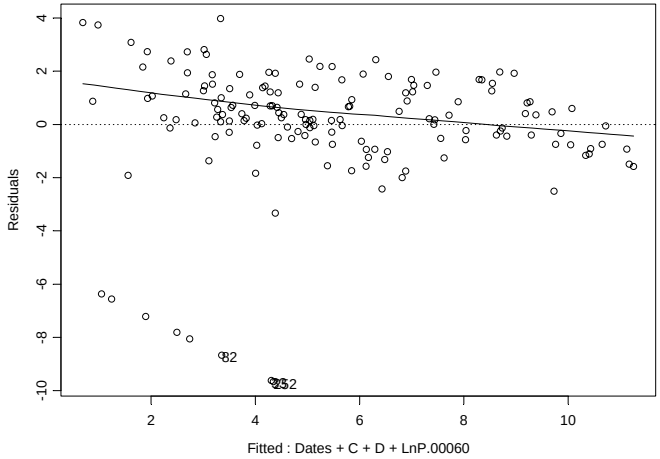


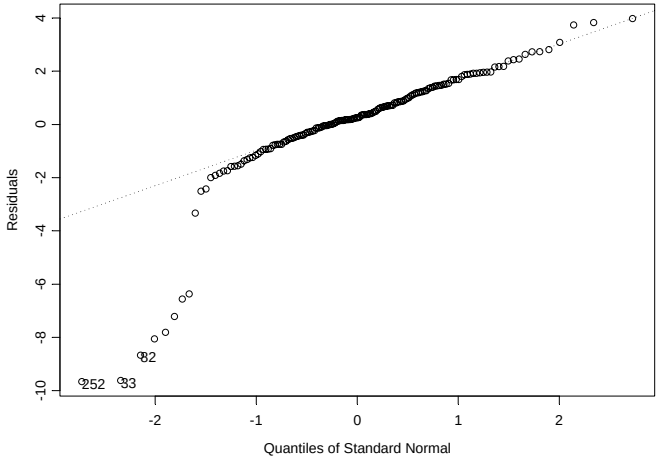
Preliminary transport equation: Do not cite

Colorado R. near Cisco, UT – Sand fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayG ~ Dates + C + D + LnP.00060, data =
      TEqCiscoDataRecalc70331G, na.action = na.exclude)
Residuals:
    Min      1Q Median    3Q   Max
 -9.664 -0.5389 0.2451 1.256 3.976

Coefficients:
               Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   2.4259    -8.3000   0.0000
      Dates   XXXXXX   0.0001     2.7571   0.0066
          C   XXXXXX   0.2703     3.5282   0.0006
          D   XXXXXX   0.3152     1.0608   0.2905
  LnP.00060   XXXXXX   0.2933     9.3546   0.0000

Residual standard error: 2.307 on 151 degrees of freedom
Multiple R-Squared: 0.5591
F-statistic: 47.88 on 4 and 151 degrees of freedom, the p-value is 0
276 observations deleted due to missing values
```



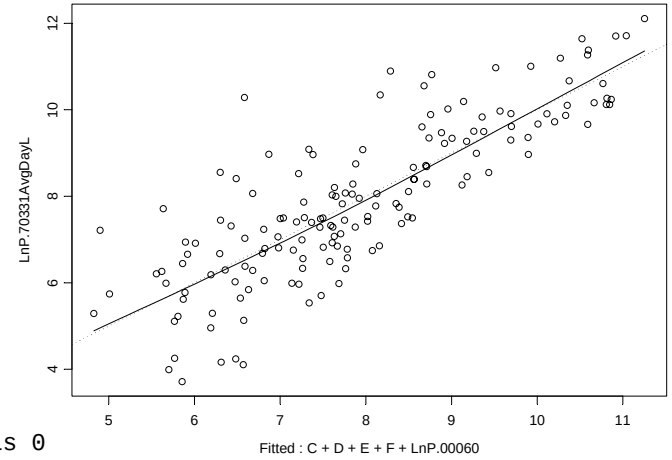


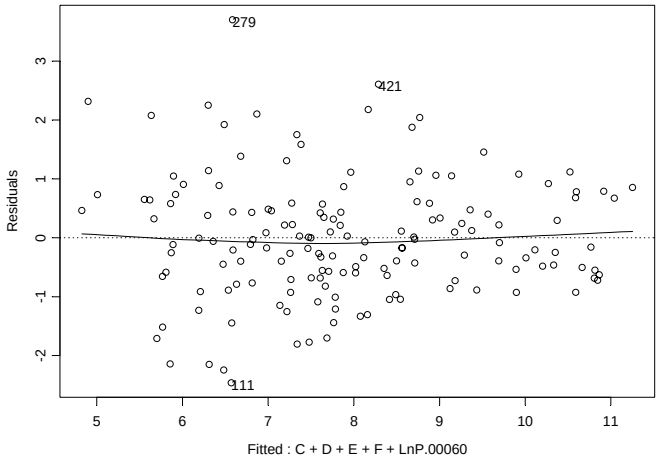


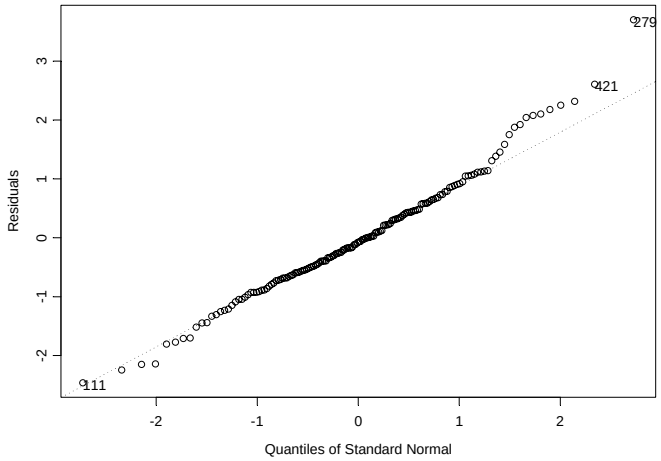
Preliminary transport equation: Do not cite

Colorado R. near Cisco, UT – Silt and clay fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayL ~ C + D + E + F + LnP.00060, data =
      TEqCiscoDataRecalc70331L, na.action = na.exclude)
Residuals:
    Min      1Q   Median     3Q   Max
 -2.463 -0.6449 -0.07665 0.5847 3.701

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   1.2754    -4.5951   0.0000
          C   XXXXXX   0.1254     0.4914   0.6239
          D   XXXXXX   0.1491    -4.7149   0.0000
          E   XXXXXX   0.1375    -1.2607   0.2094
          F   XXXXXX   0.1275    -6.4981   0.0000
  LnP.00060   XXXXXX   0.1491    10.4838   0.0000

Residual standard error: 1.037 on 150 degrees of freedom
Multiple R-Squared: 0.6905
F-statistic: 66.94 on 5 and 150 degrees of freedom, the p-value is 0
276 observations deleted due to missing values
```



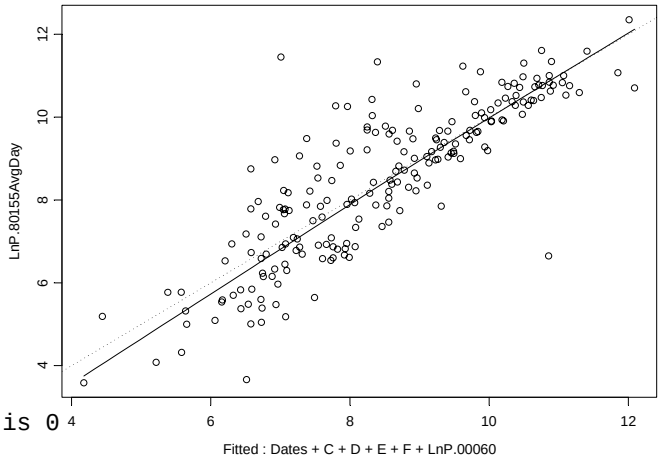


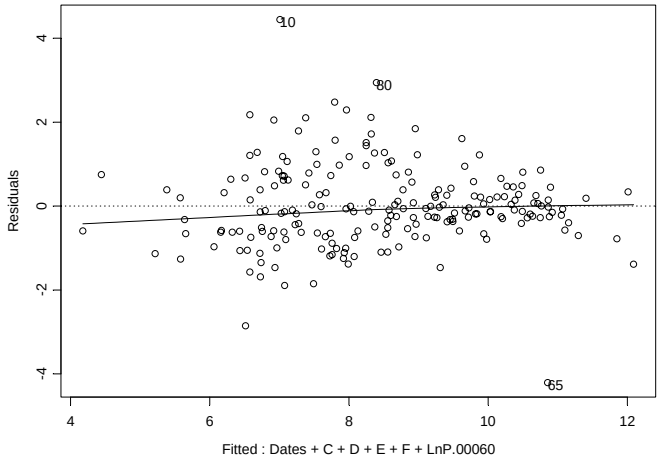


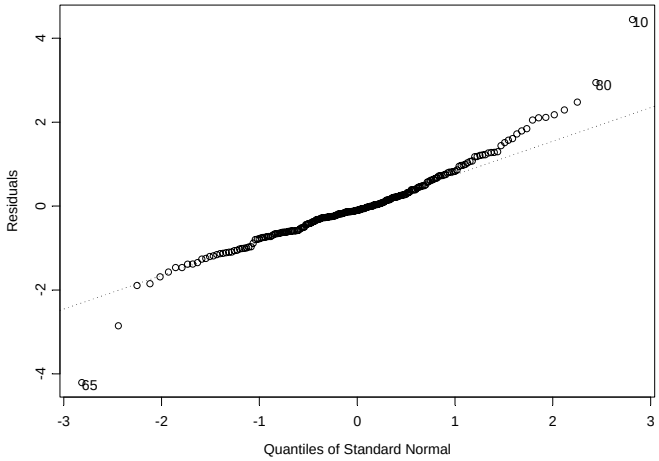
Preliminary transport equation: Do not cite

Green R. near Jensen, UT – Total fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.80155AvgDay ~ Dates + C + D + E + F + LnP.00060, data =
      TEqJensenDataRecalc80155, na.action = na.exclude)
Residuals:
    Min      1Q   Median     3Q   Max
 -4.207 -0.5953 -0.09808 0.4832 4.442

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   1.2185    -5.6153   0.0000
      Dates   XXXXXX   0.0000    -6.2710   0.0000
          C   XXXXXX   0.1195     3.0891   0.0023
          D   XXXXXX   0.1324    -3.3227   0.0011
          E   XXXXXX   0.1242     0.2389   0.8114
          F   XXXXXX   0.1149    -5.4920   0.0000
  LnP.00060   XXXXXX   0.1463    12.8191   0.0000

Residual standard error: 0.9967 on 198 degrees of freedom
Multiple R-Squared: 0.7241
F-statistic: 86.63 on 6 and 198 degrees of freedom, the p-value is 0
35 observations deleted due to missing values
```



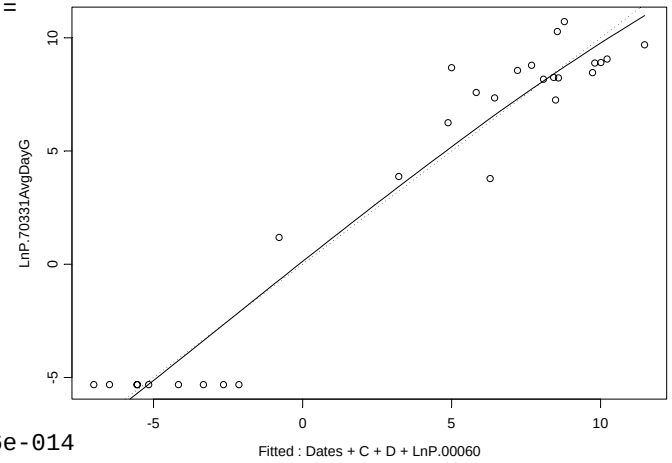


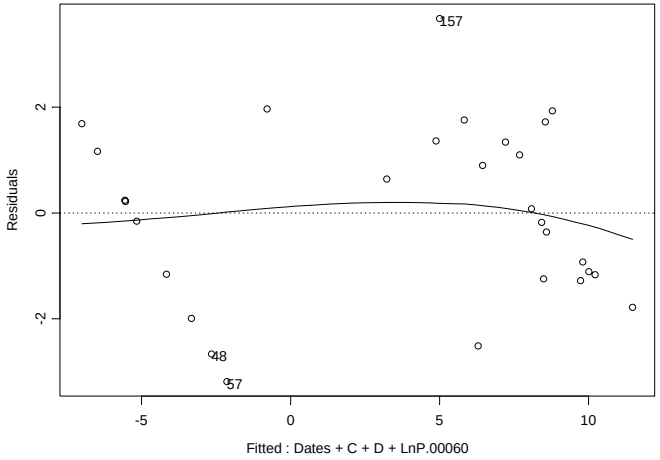


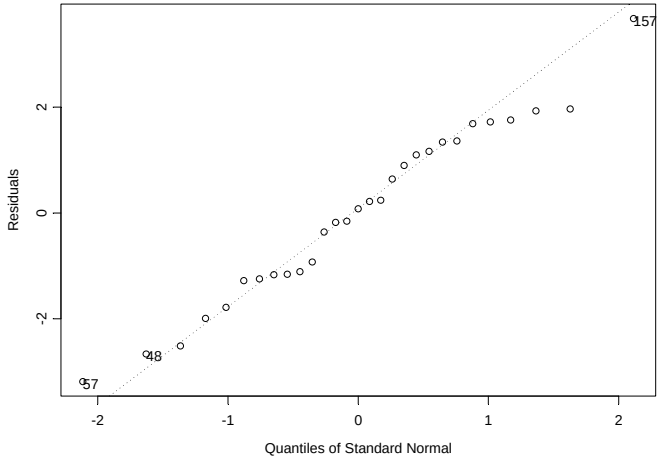
Preliminary transport equation: Do not cite

Green R. near Jensen, UT – Sand fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayG ~ Dates + C + D + LnP.00060, data =
      TEqJensenDataRecalc70331G, na.action = na.exclude)
Residuals:
    Min     1Q  Median    3Q   Max
 -3.188 -1.167 0.07725 1.336 3.672

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   4.3702    -7.6682   0.0000
      Dates   XXXXXX   0.0001     5.0449   0.0000
          C   XXXXXX   0.9571     2.0707   0.0493
          D   XXXXXX   0.6416     3.6967   0.0011
  LnP.00060   XXXXXX   0.5093     7.4666   0.0000

Residual standard error: 1.784 on 24 degrees of freedom
Multiple R-Squared: 0.9339
F-statistic: 84.71 on 4 and 24 degrees of freedom, the p-value is 8.56e-014
211 observations deleted due to missing values
```



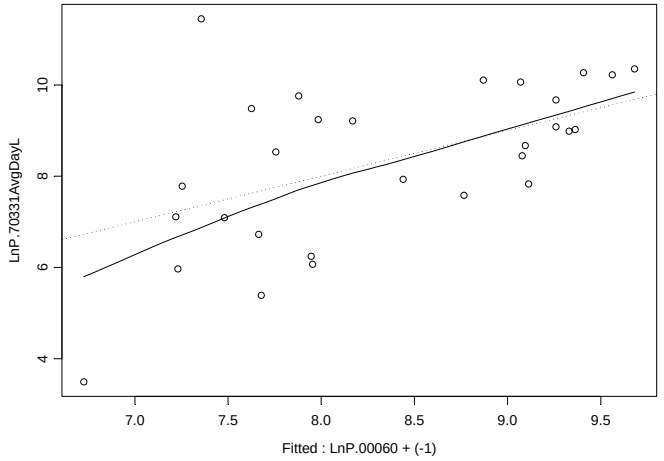


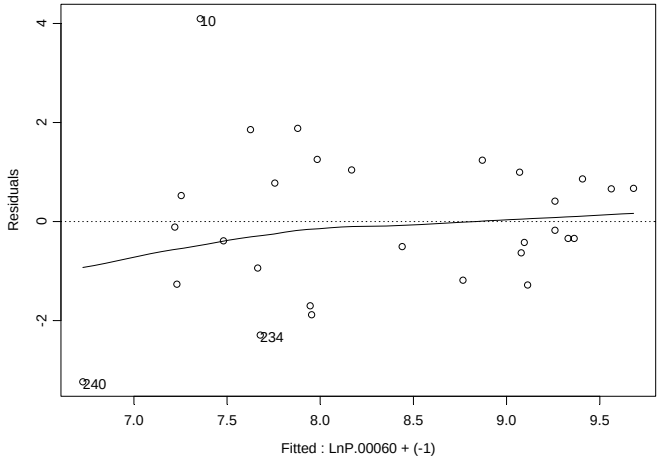


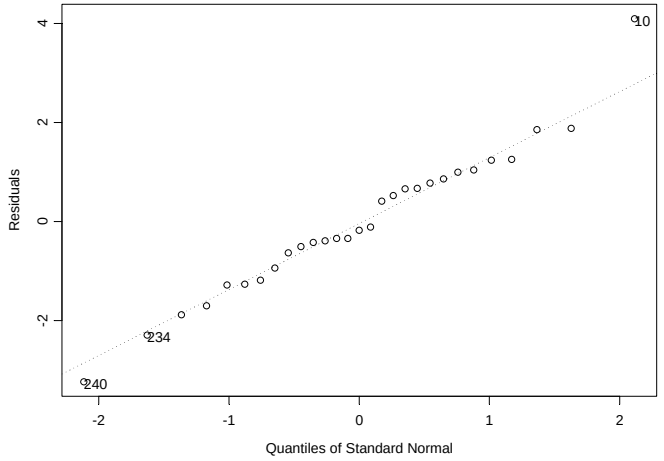
Preliminary transport equation: Do not cite

Green R. near Jensen, UT – Silt and clay fraction of suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayL ~ LnP.00060 + (-1), data =
      TEqJensenDataRecalc70331L, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q     Max
 -3.237 -0.9378 -0.1781 0.8583 4.094

Coefficients:
            Value Std. Error t value Pr(>|t|)
LnP.00060  XXXXXX   0.0317    30.7475  0.0000

Residual standard error: 1.471 on 28 degrees of freedom
Multiple R-Squared: 0.9712
F-statistic: 945.4 on 1 and 28 degrees of freedom, the p-value is 0
211 observations deleted due to missing values
```



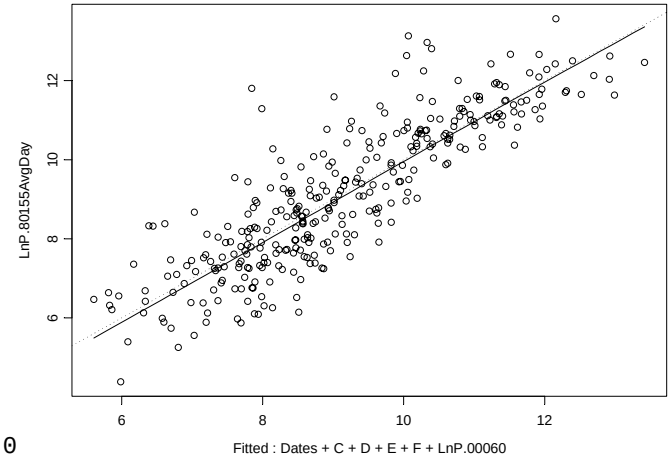


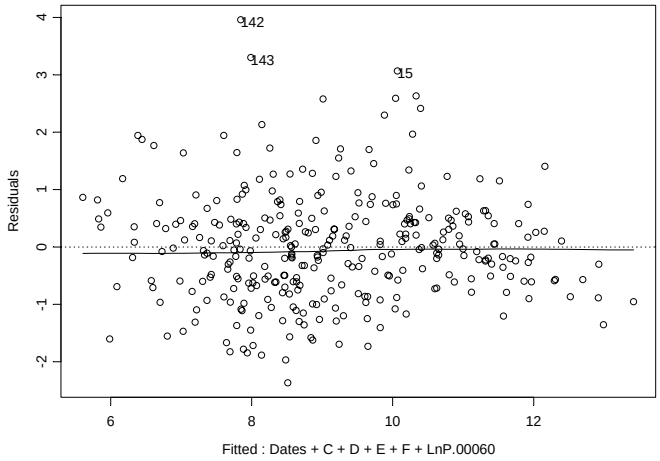


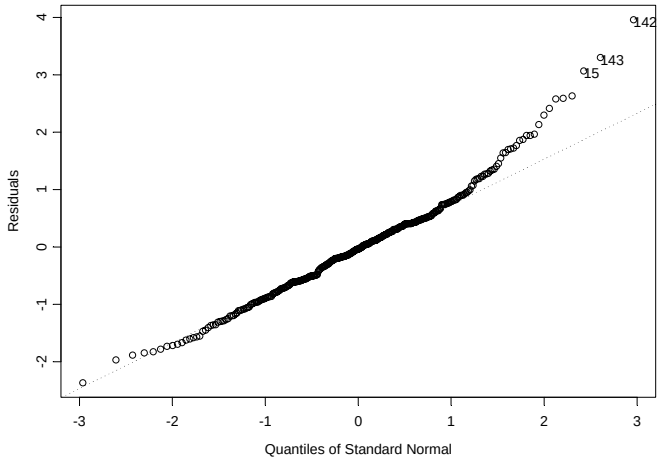
Preliminary transport equation: Do not cite

Green R. at Green River, UT – Total suspended sediment load

```
      *** Linear Model ***
Call: lm(formula = LnP.80155AvgDay ~ Dates + C + D + E + F + LnP.00060, data =
      TEqGreenDataRecalc80155, na.action = na.exclude)
Residuals:
    Min     1Q   Median     3Q   Max
 -2.369 -0.61 -0.03739 0.4689 3.959

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)  XXXXXX     0.9004  -8.8555   0.0000
      Dates  XXXXXX     0.0000  -7.7953   0.0000
          C  XXXXXX     0.0815  -1.2884   0.1985
          D  XXXXXX     0.0979  -6.1570   0.0000
          E  XXXXXX     0.0845   2.2409   0.0257
          F  XXXXXX     0.0805  -6.6323   0.0000
  LnP.00060  XXXXXX     0.1045  19.7835   0.0000

Residual standard error: 0.9485 on 321 degrees of freedom
Multiple R-Squared: 0.7422
F-statistic: 154 on 6 and 321 degrees of freedom, the p-value is 0
128 observations deleted due to missing values
```



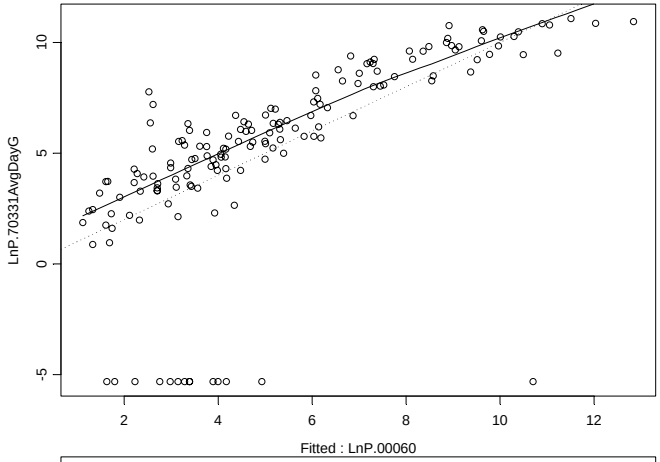


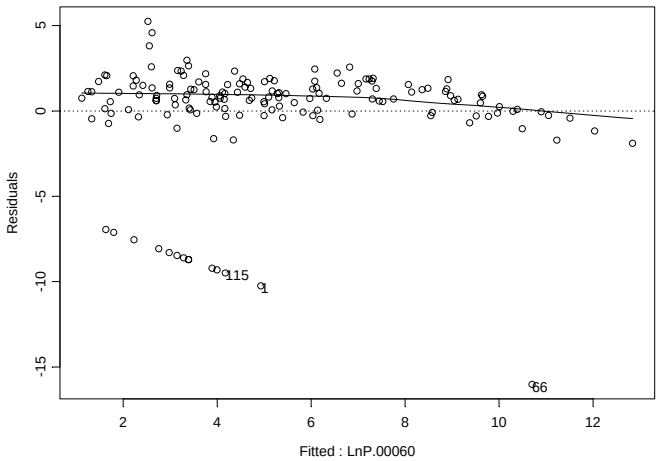


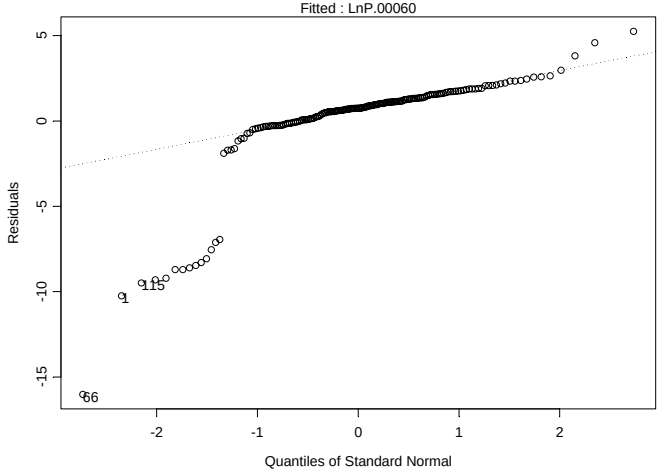
Preliminary transport equation: Do not cite

Green R. at Green River, UT – Sand fraction of suspended sediment load

```
             *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayG ~ LnP.00060, data = TEqGreenDataRecalc70331G,
       na.action = na.exclude)
Residuals:
    Min      1Q Median    3Q   Max
 -16.02 -0.1336 0.7413 1.425 5.246

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   2.8671    -9.2655   0.0000
  LnP.00060   XXXXXX   0.3347    11.1202   0.0000

Residual standard error: 3.085 on 157 degrees of freedom
Multiple R-Squared: 0.4406
F-statistic: 123.7 on 1 and 157 degrees of freedom, the p-value is 0
297 observations deleted due to missing values
```



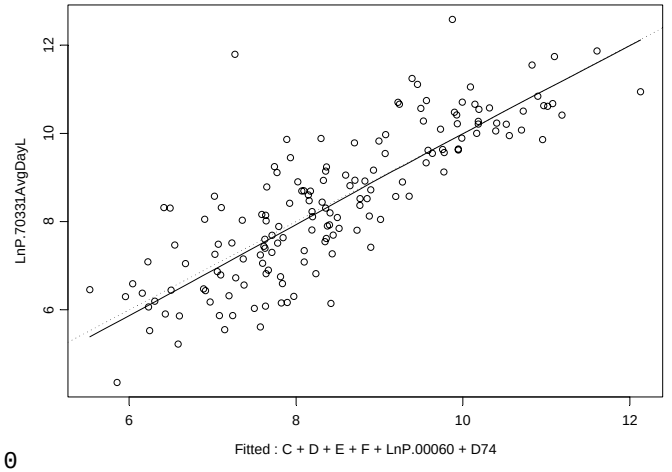


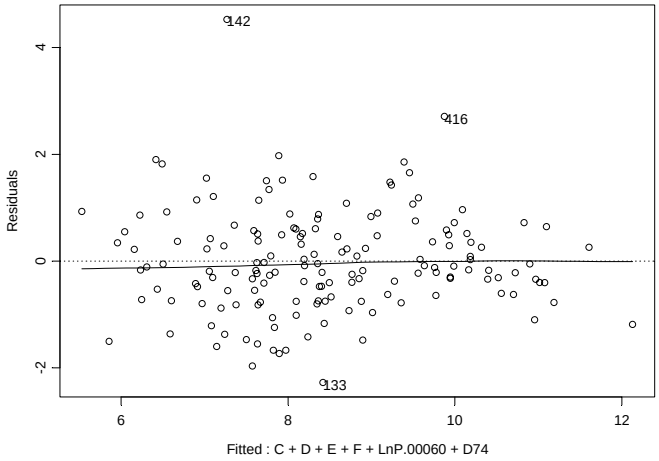


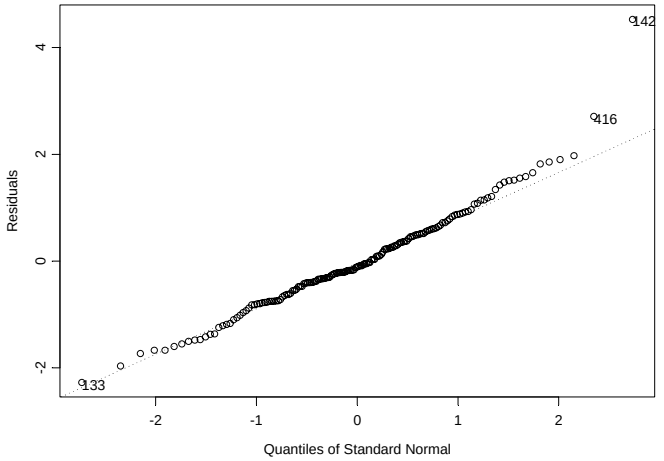
Preliminary transport equation: Do not cite

Green R. at Green River, UT – Silt and clay fraction of suspended sediment load

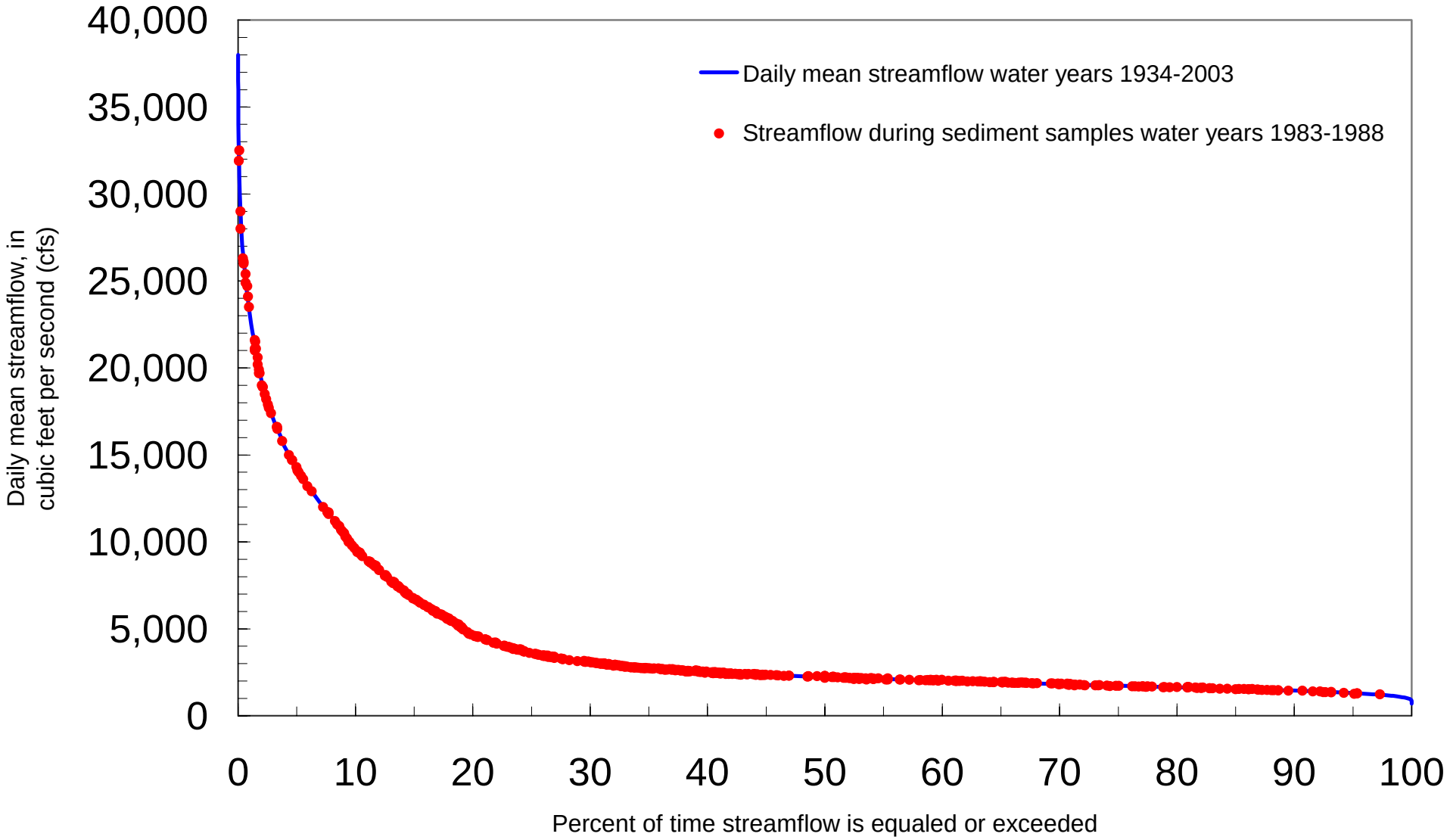
```
      *** Linear Model ***
Call: lm(formula = LnP.70331AvgDayL ~ C + D + E + F + LnP.00060 + D74, data =
      TEqGreenDataRecalc70331L, na.action = na.exclude)
Residuals:
    Min      1Q  Median      3Q   Max
 -2.275 -0.6176 -0.1117 0.5319 4.526

Coefficients:
              Value Std. Error  t value Pr(>|t|)
(Intercept)   XXXXXX   1.3126    -6.0565   0.0000
          C   XXXXXX   0.1244    -1.2832   0.2014
          D   XXXXXX   0.1386    -3.2946   0.0012
          E   XXXXXX   0.1245     0.6567   0.5124
          F   XXXXXX   0.1201    -5.6849   0.0000
  LnP.00060   XXXXXX   0.1522    12.2456   0.0000
        D74   XXXXXX   0.1723     3.4744   0.0007

Residual standard error: 0.9731 on 152 degrees of freedom
Multiple R-Squared: 0.6737
F-statistic: 52.29 on 6 and 152 degrees of freedom, the p-value is 0
297 observations deleted due to missing values
```



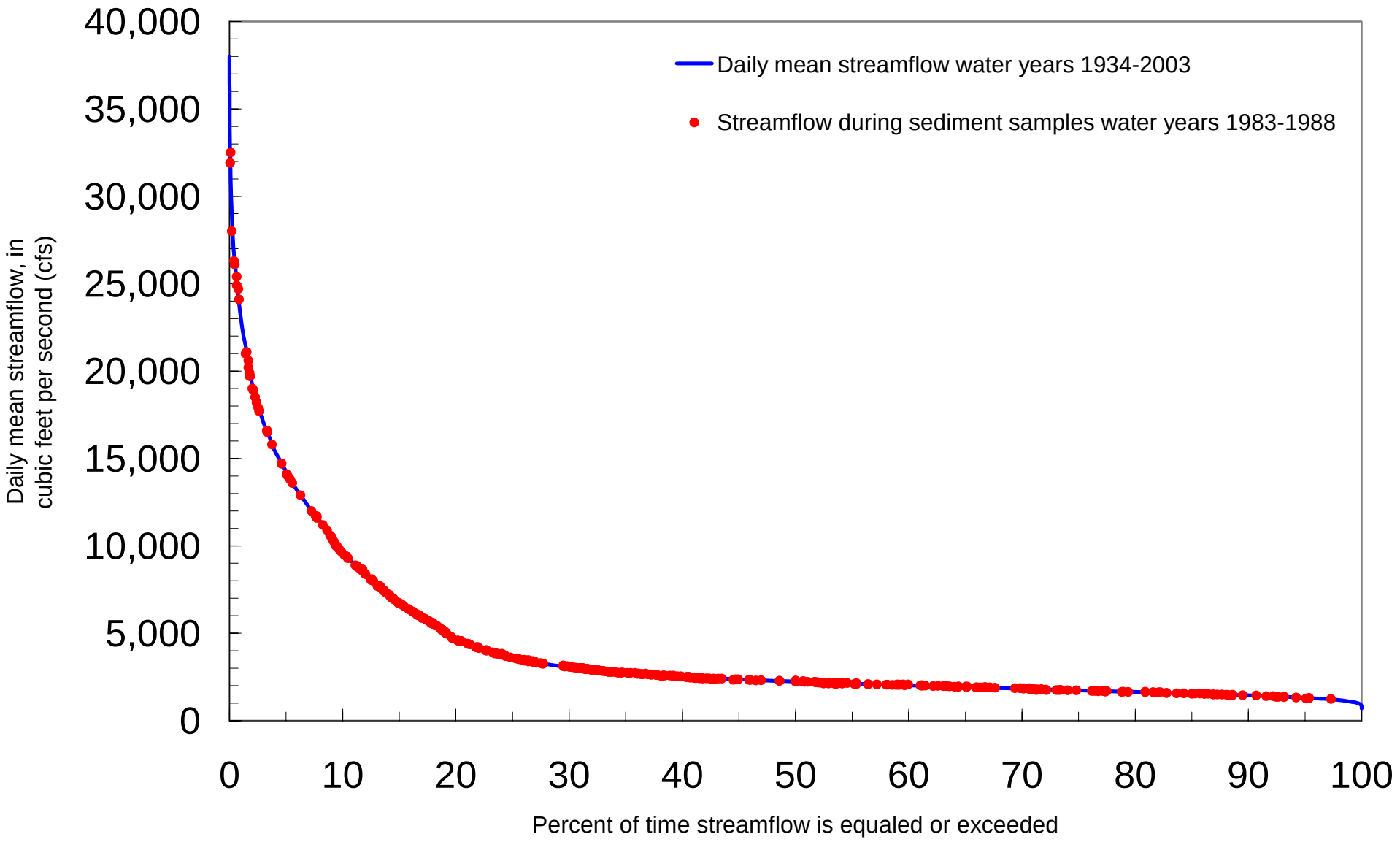




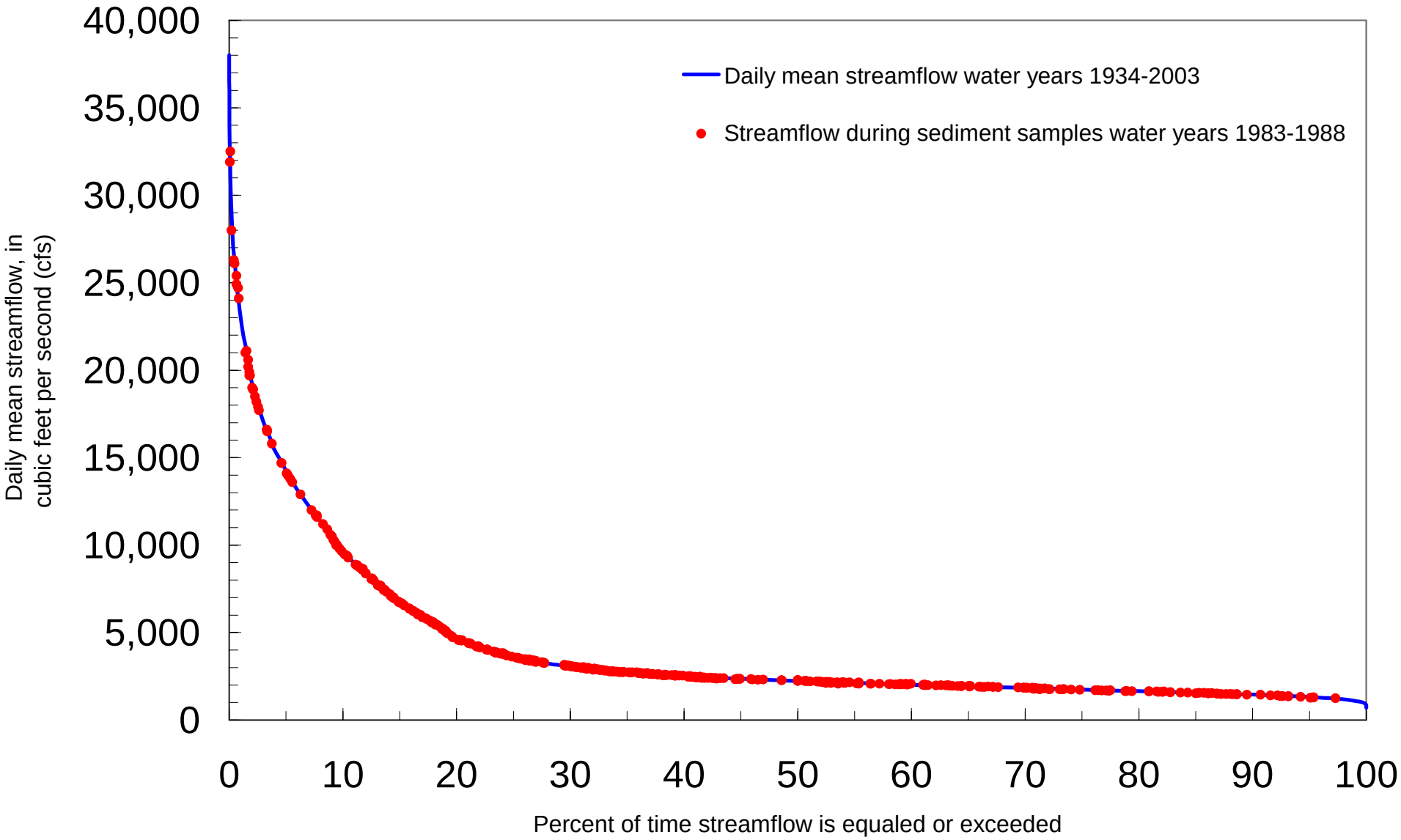
Appendix 2: Flow-duration curves and refined sediment sample distributions



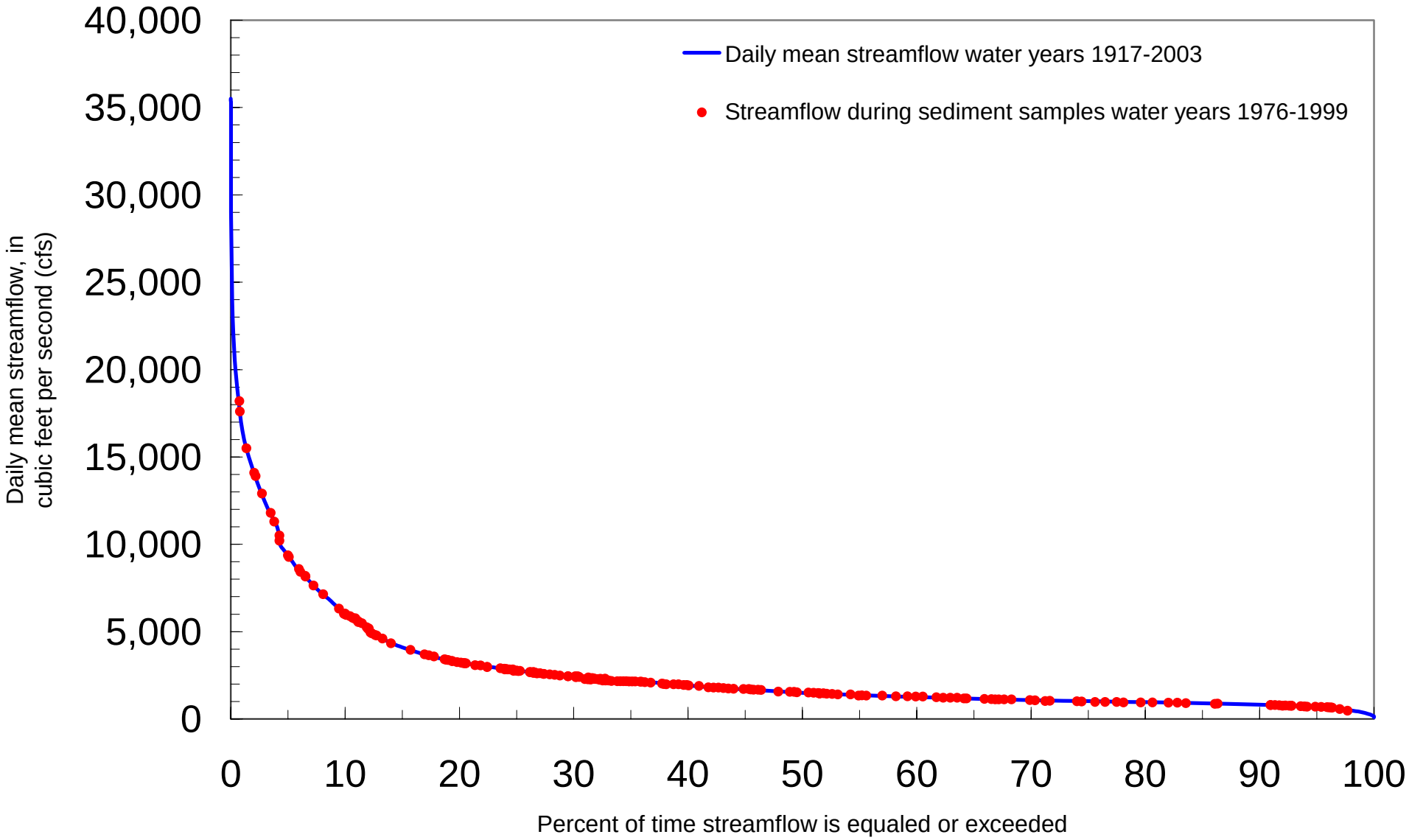
Flow-duration curve and refined sample distribution for total suspended-sediment load at station 09095500, Colorado River near Cameo, Colorado.



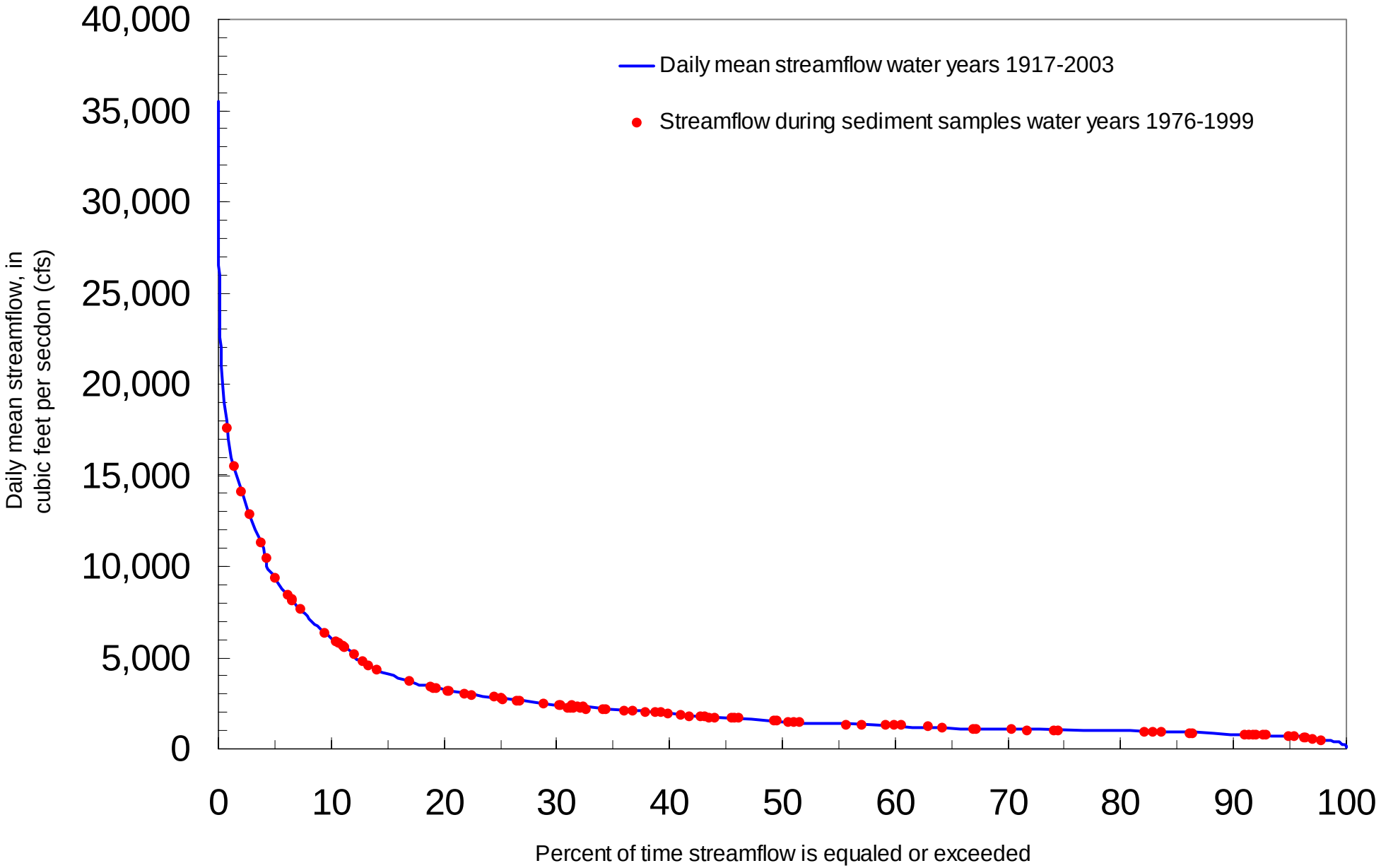
Flow-duration curve and refined sample distribution for sand fraction of suspended-sediment load at station 09095500, Colorado River near Cameo, Colorado.



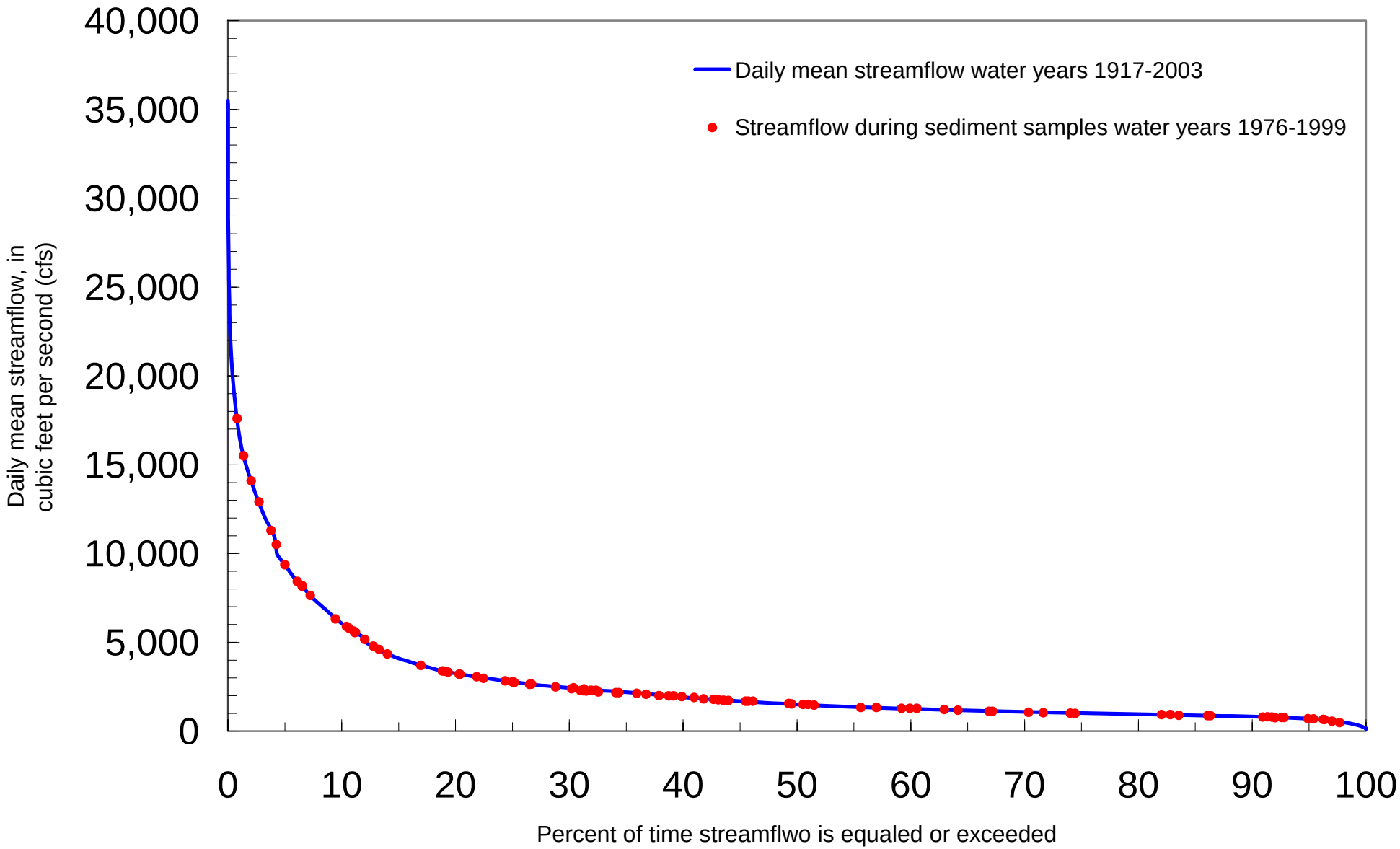
Flow-duration curve and refined sample distribution for silt and clay fraction of suspended-sediment load at station 09095500, Colorado River near Cameo, Colorado.



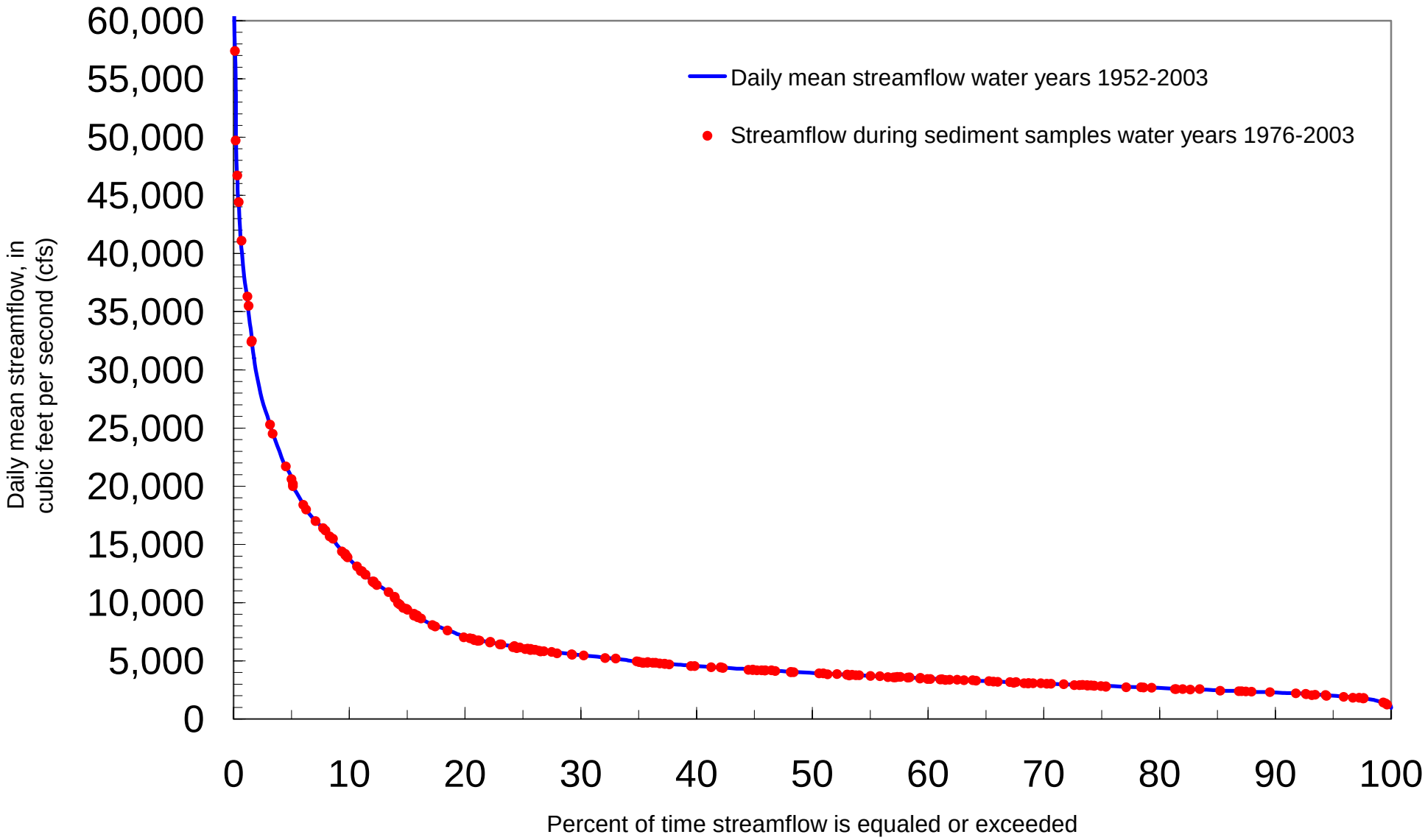
Flow-duration curve and refined sample distribution for total suspended-sediment load at station 09152500, Gunnison River near Grand Junction, Colorado.



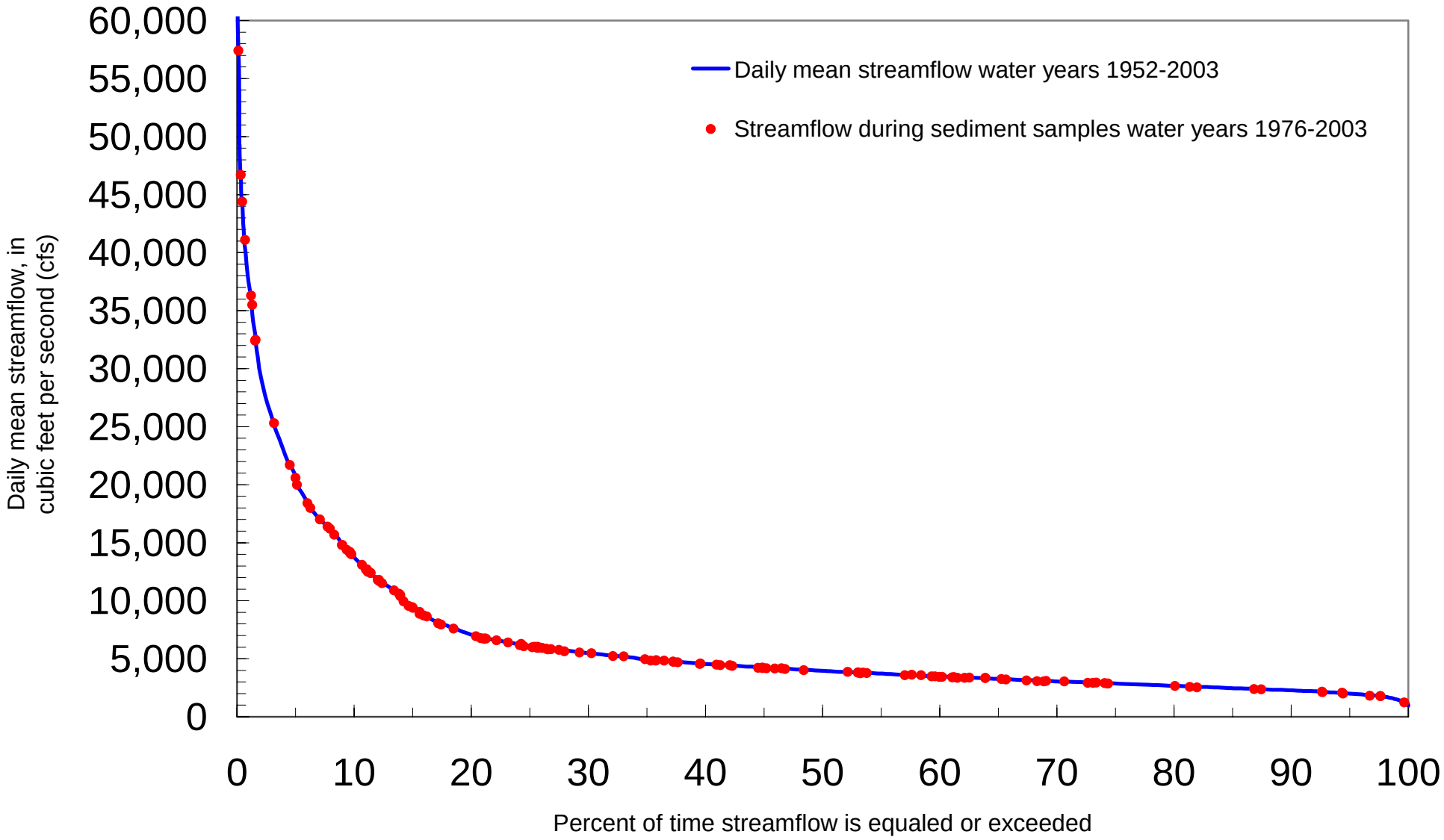
Flow-duration curve and refined sample distribution for sand fraction of suspended-sediment load at station 09152500, Gunnison River near Grand Junction, Colorado.



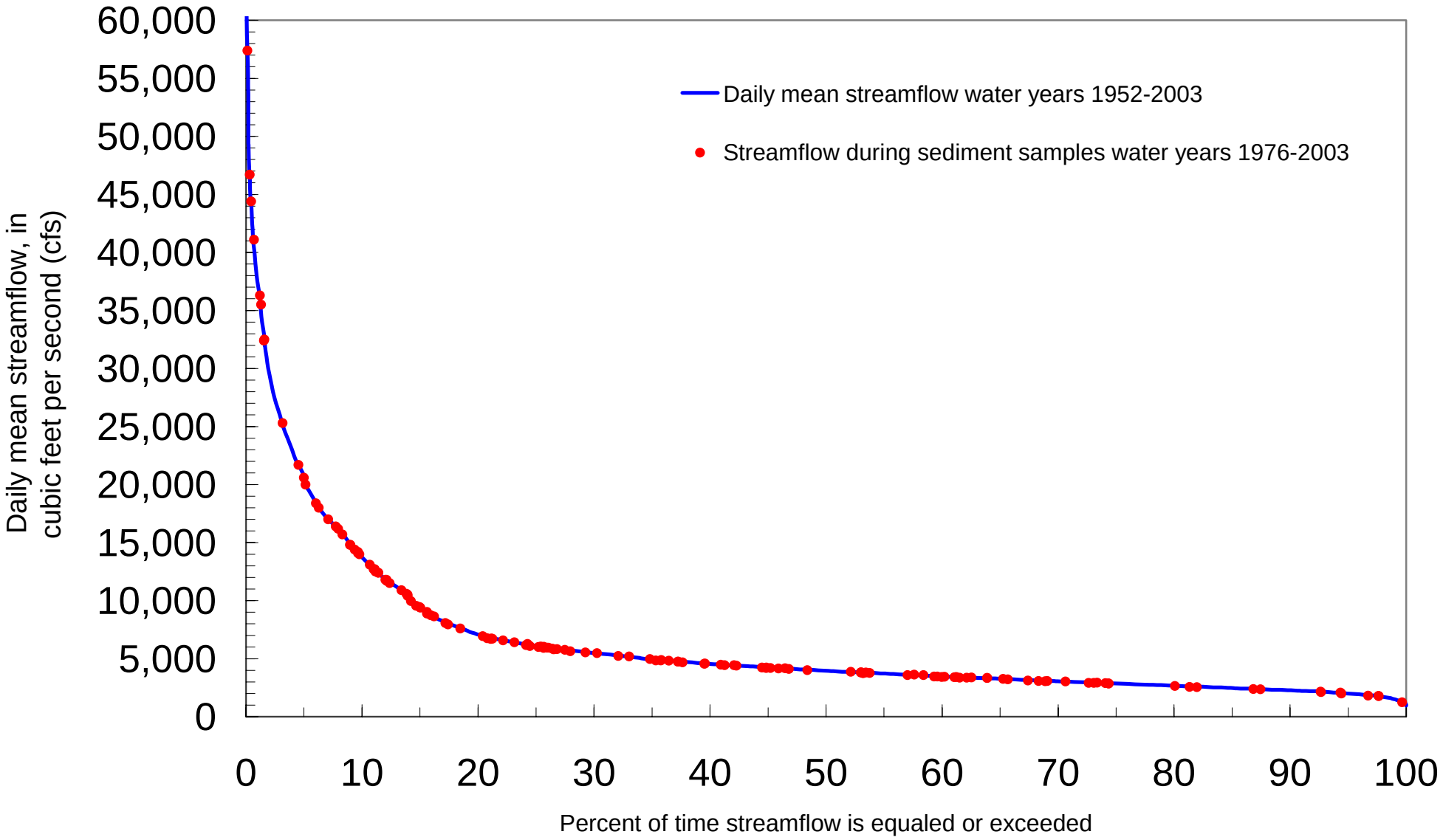
Flow-duration curve and refined sample distribution for silt and clay fraction of suspended-sediment load at station 09152500, Gunnison River near Grand Junction, Colorado.



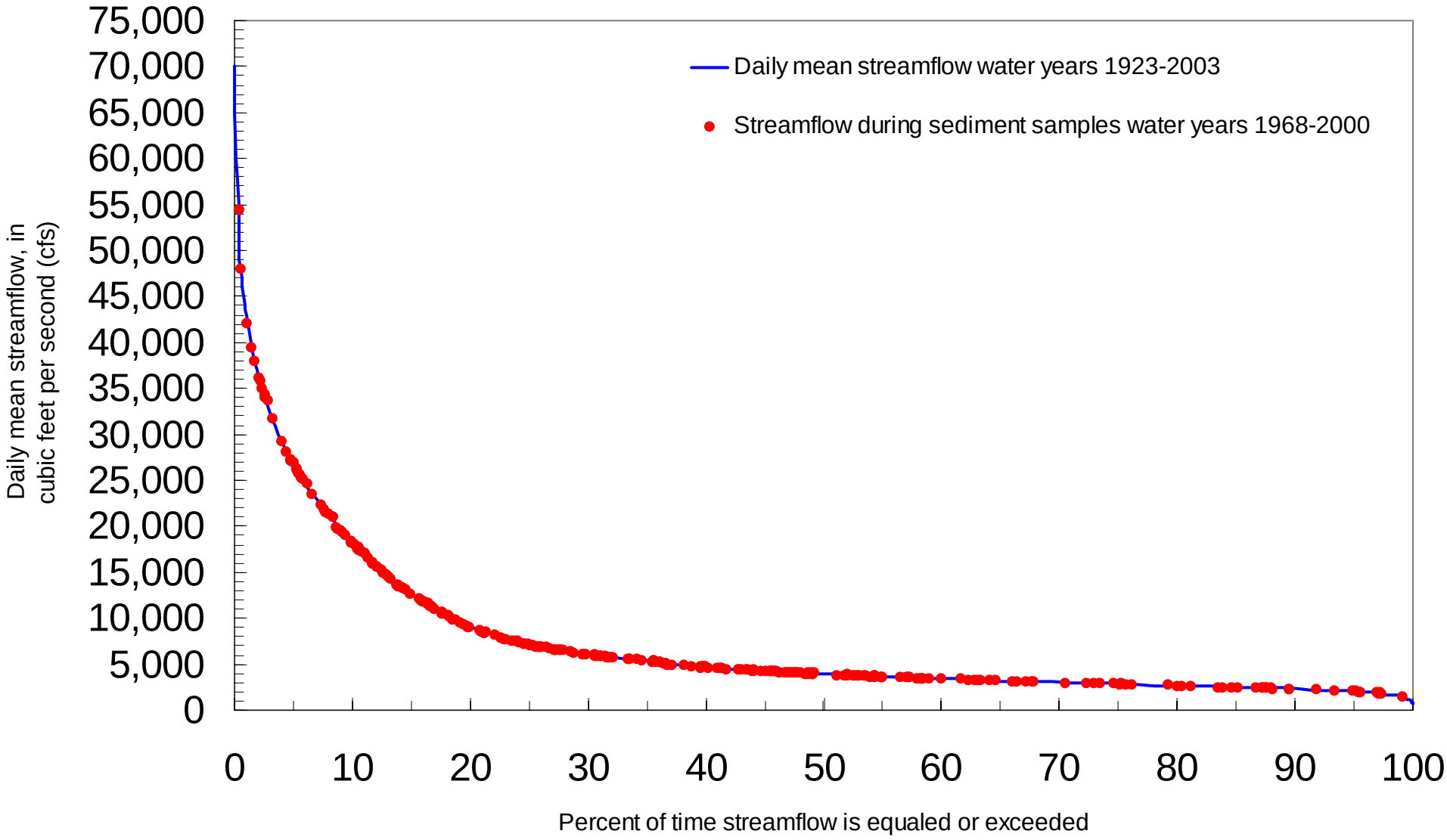
Flow-duration curve and refined sample distribution for total suspended-sediment load at station 09163500, Colorado River near Colorado-Utah state line.



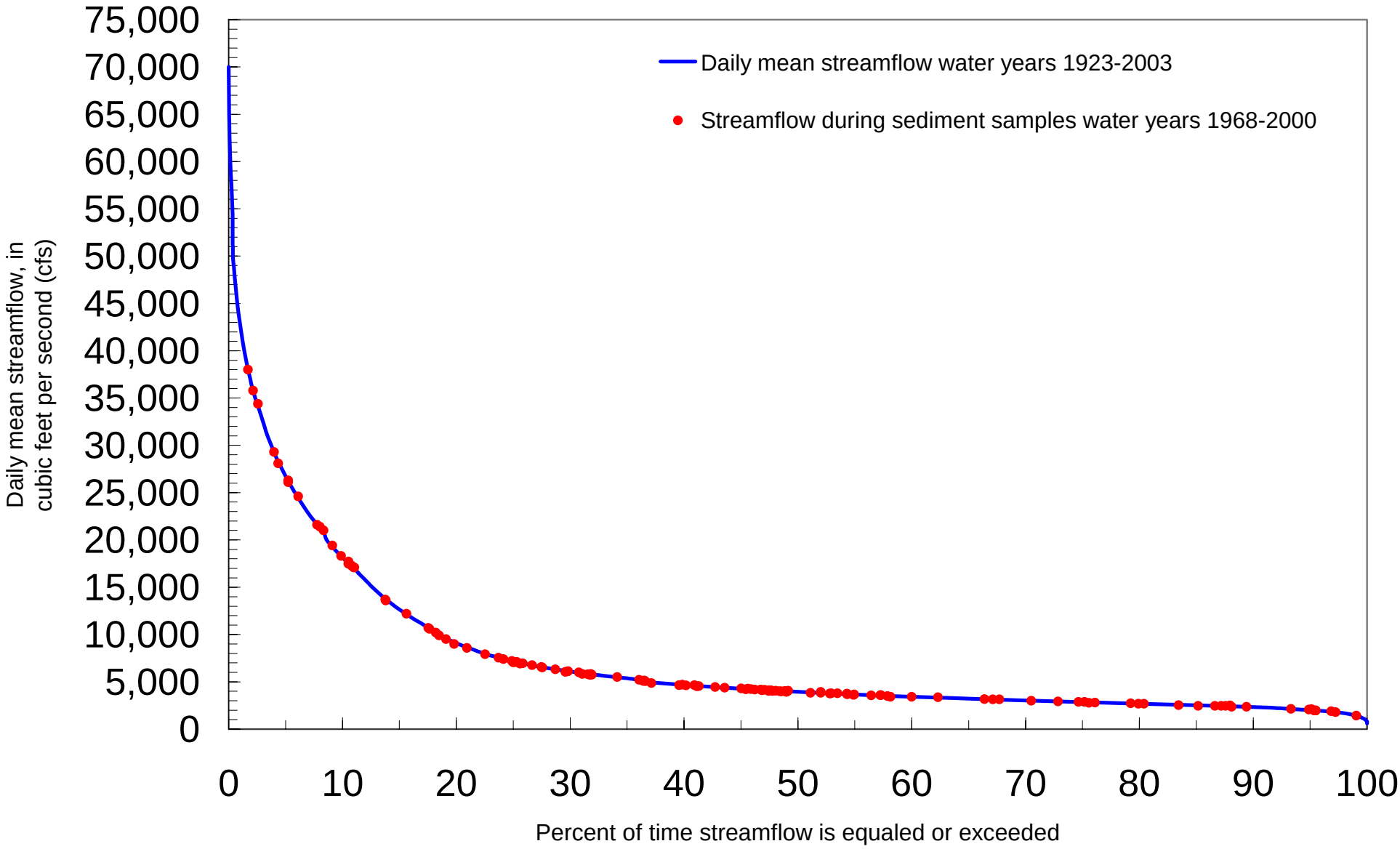
Flow-duration curve and refined sample distribution for sand fraction of suspended-sediment load at station 09163500, Colorado River near Colorado-Utah state line.



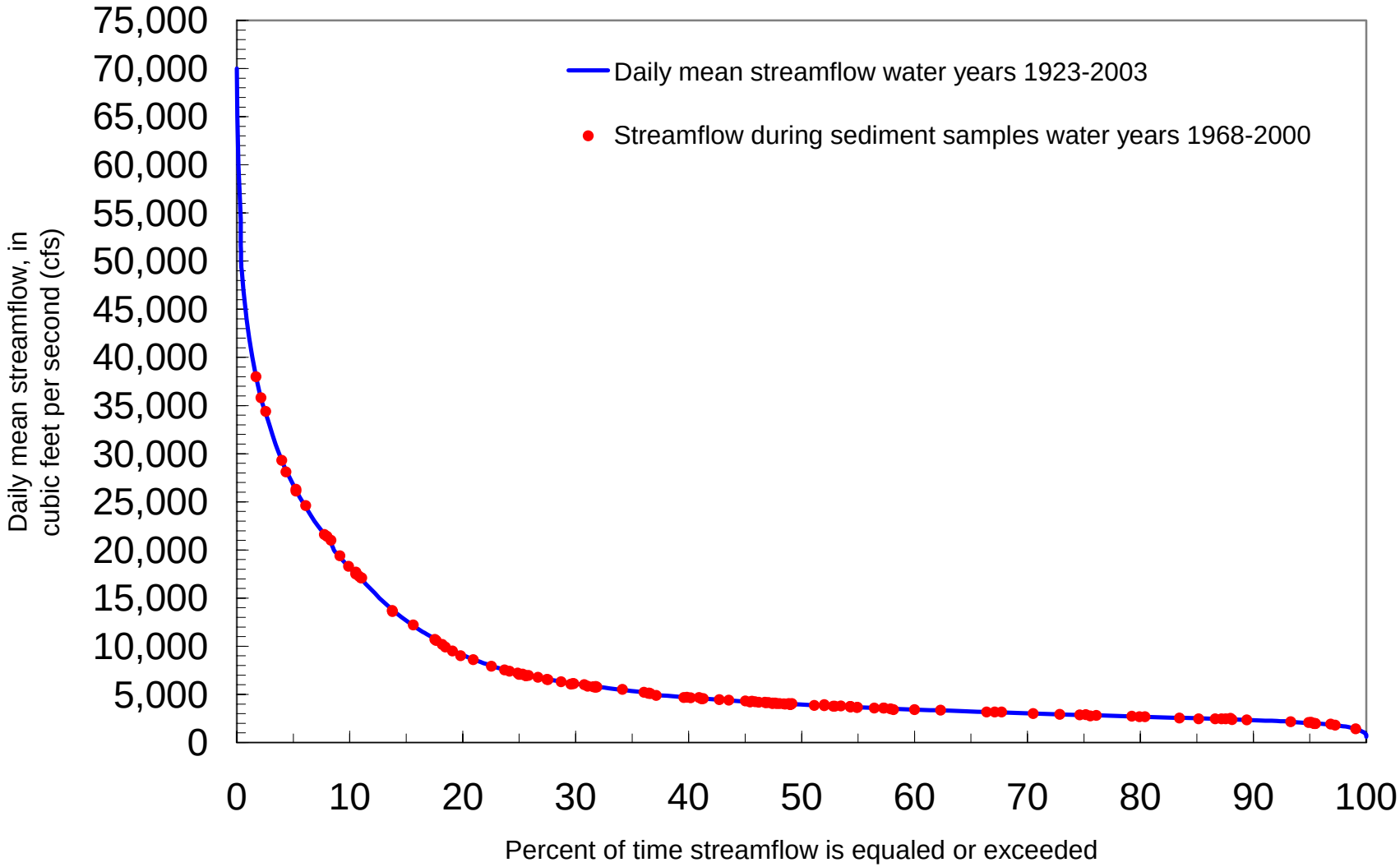
Flow-duration curve and refined sample distribution for silt and clay fraction of suspended-sediment load at station 09163500, Colorado River near Colorado-Utah state line.



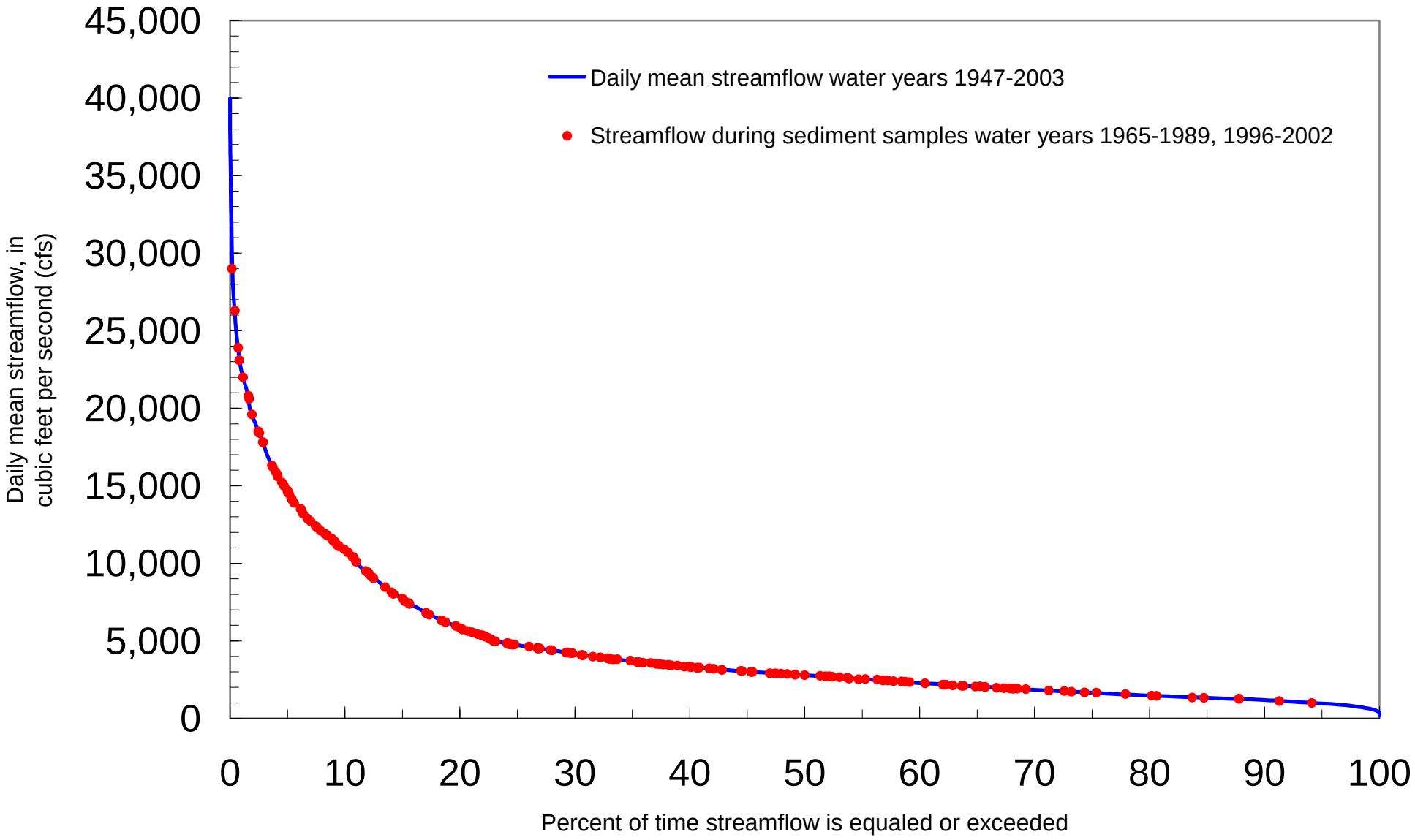
Flow-duration curve and refined sample distribution for total suspended-sediment load at station 09180500, Colorado River near Cisco, Utah.



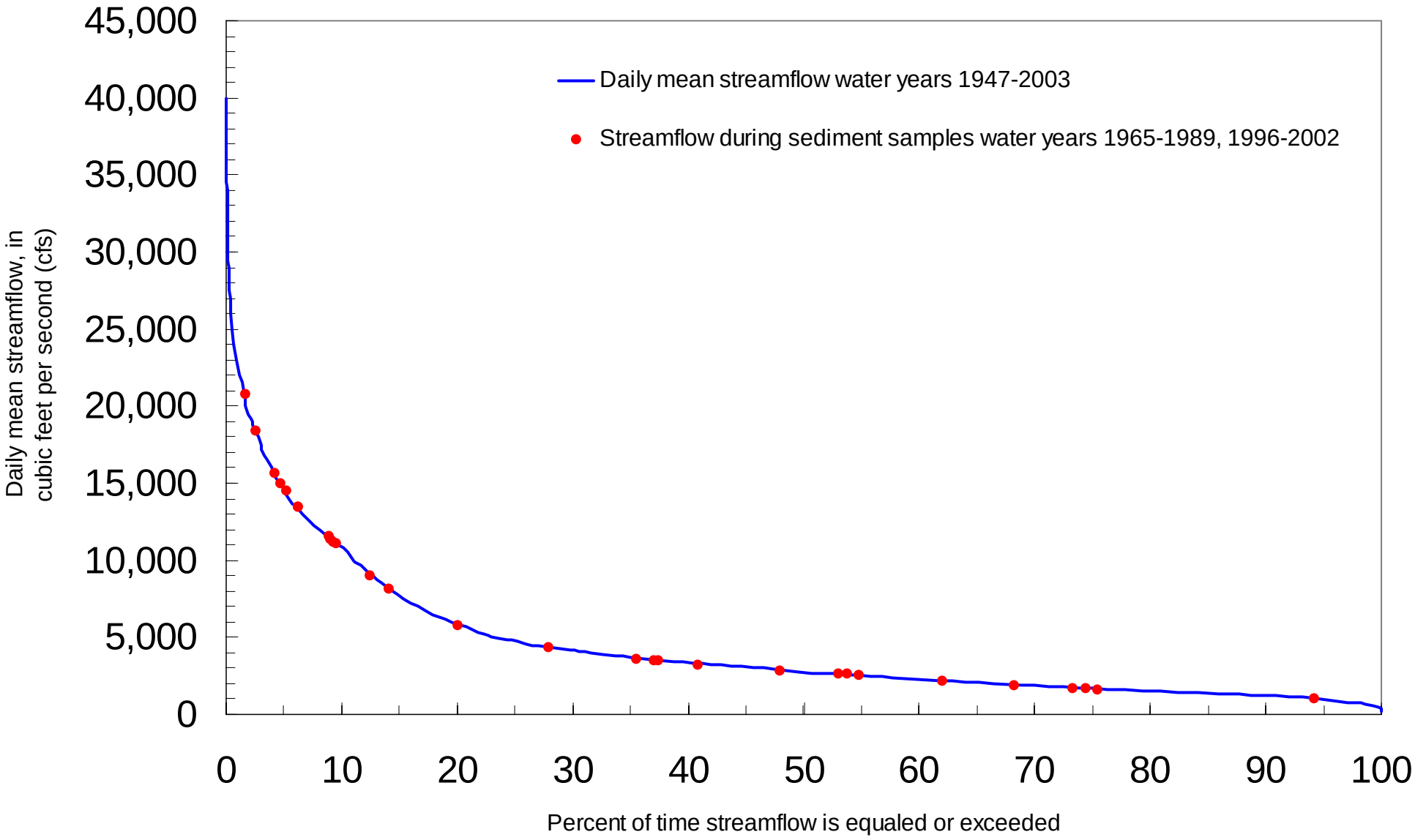
Flow-duration curve and refined sample distribution for sand fraction of suspended-sediment load at station 09180500, Colorado River near Cisco, Utah.



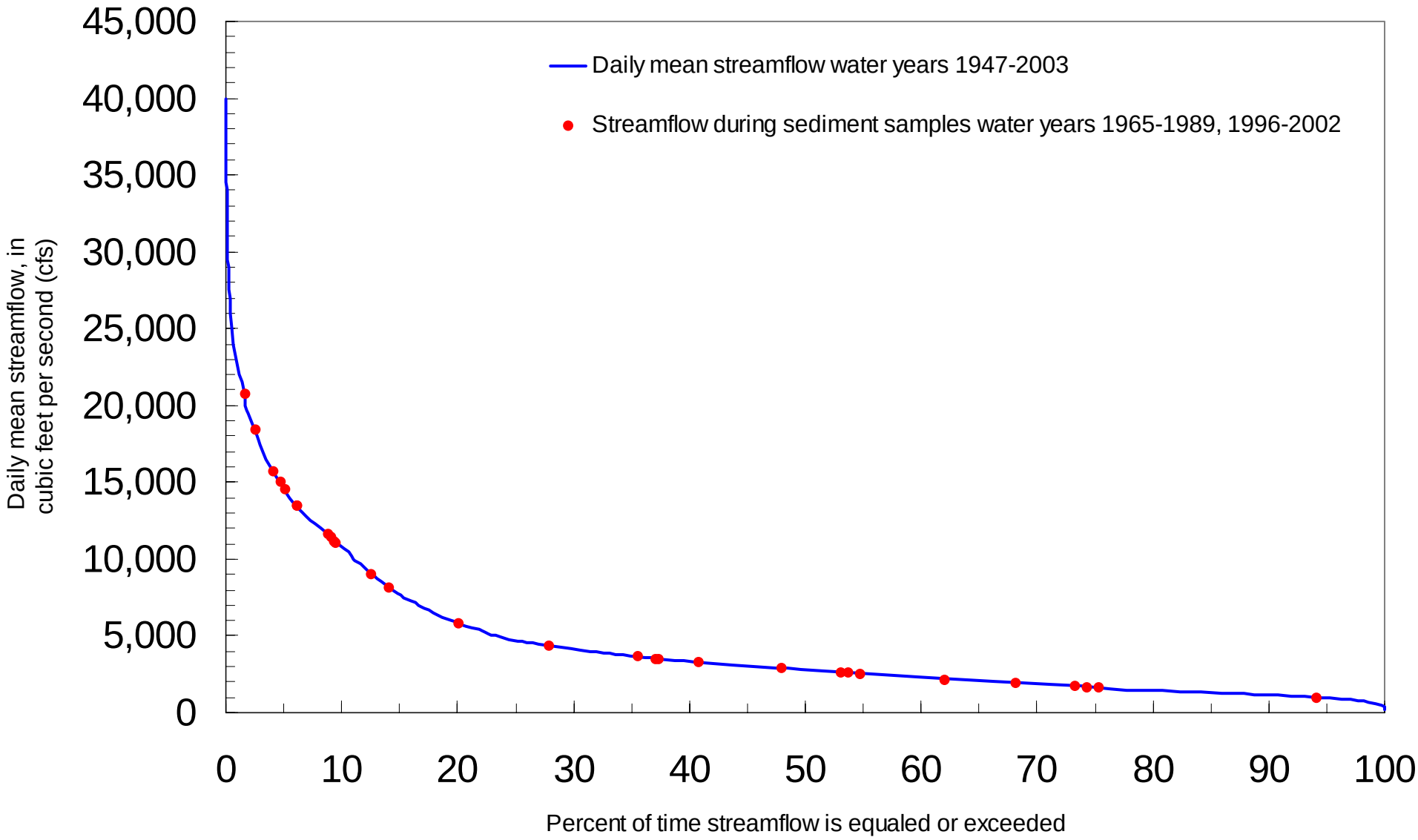
Flow-duration curve and refined sample distribution for silt and clay fraction of suspended-sediment load at station 09180500, Colorado River near Cisco, Utah.



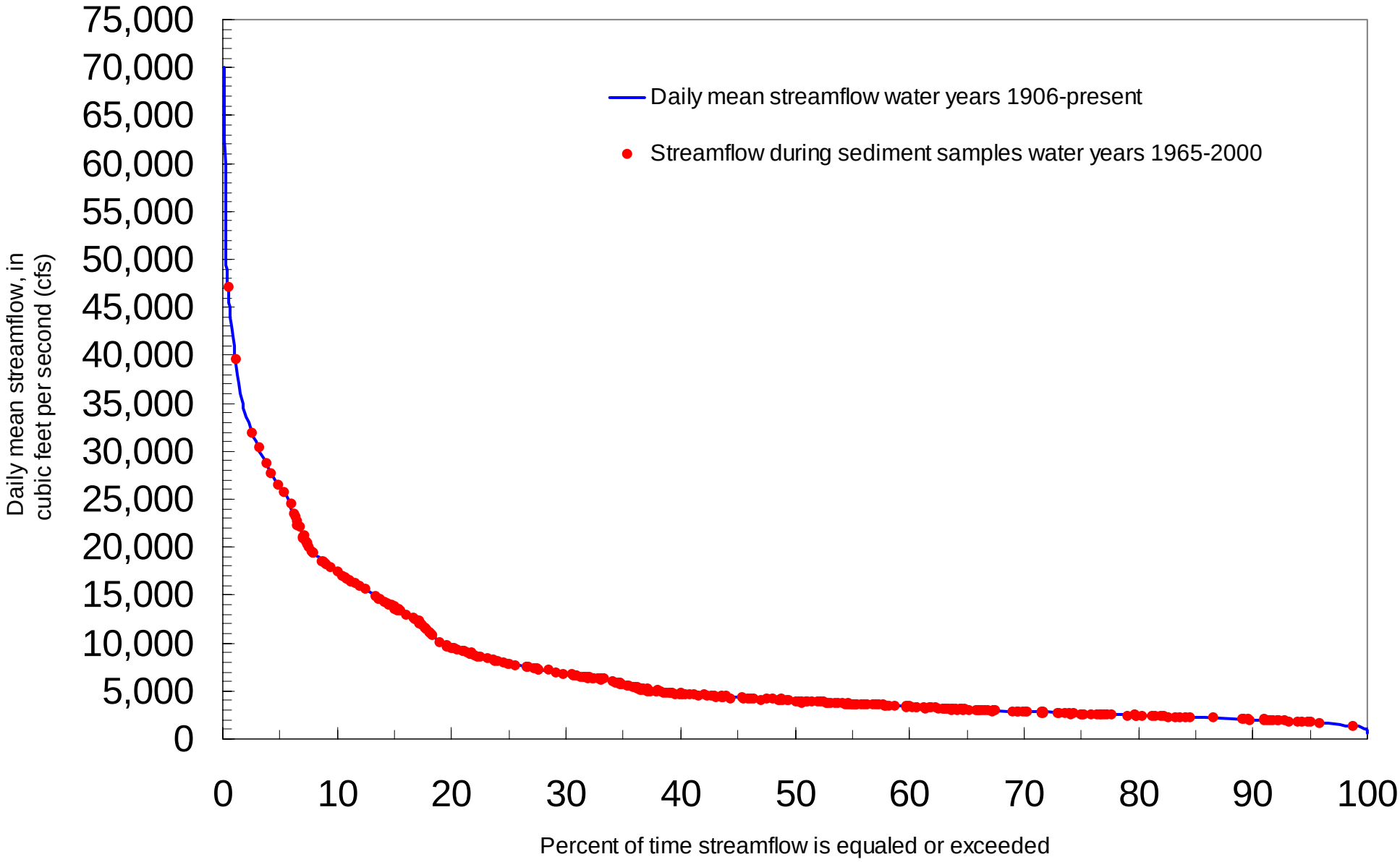
Flow-duration curve and refined sample distribution for total suspended-sediment load at station 09261000, Green River near Jensen, Utah.



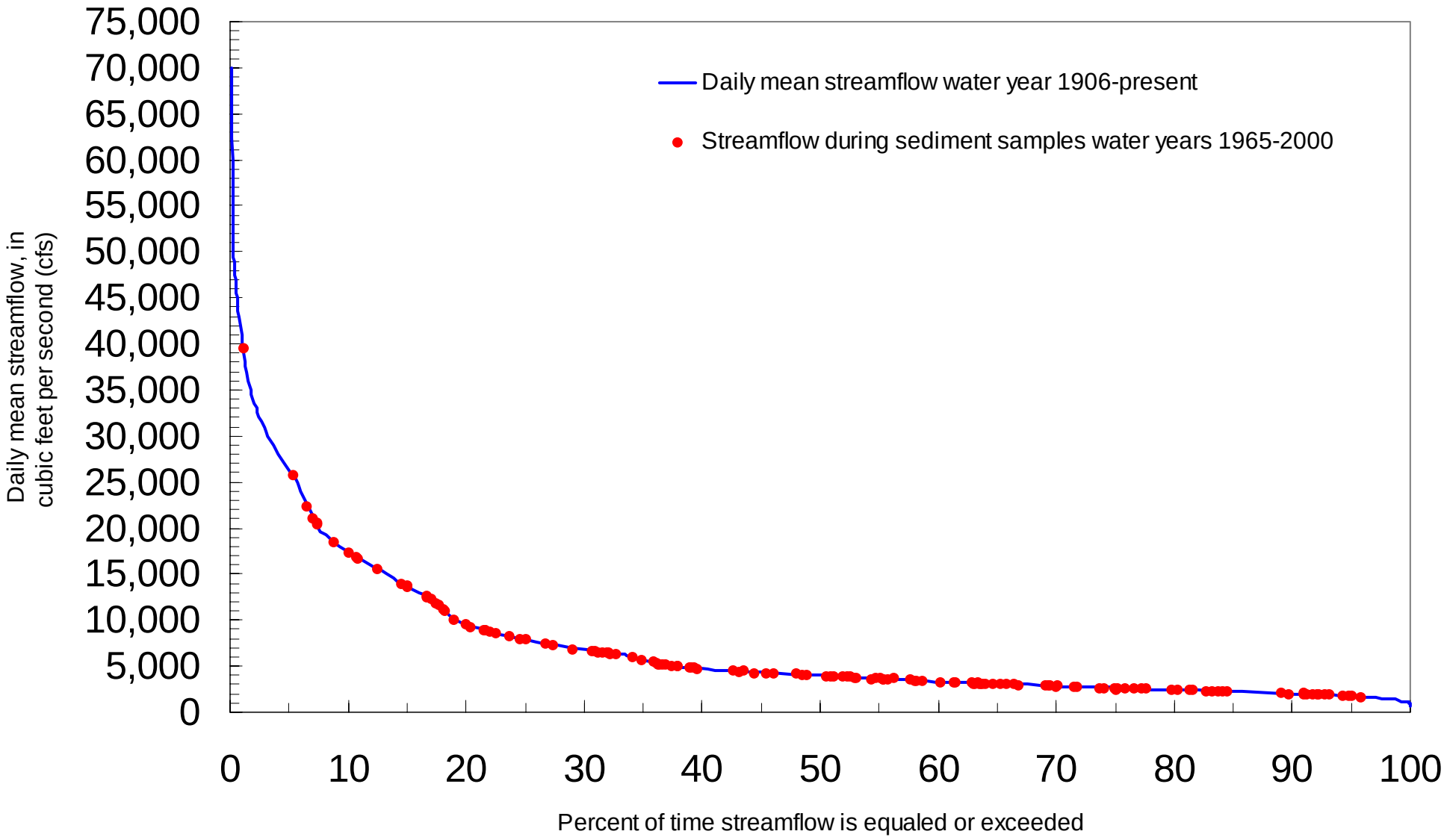
Flow-duration curve and refined sample distribution for sand fraction of suspended-sediment load at station 09261000, Green River near Jensen, Utah.



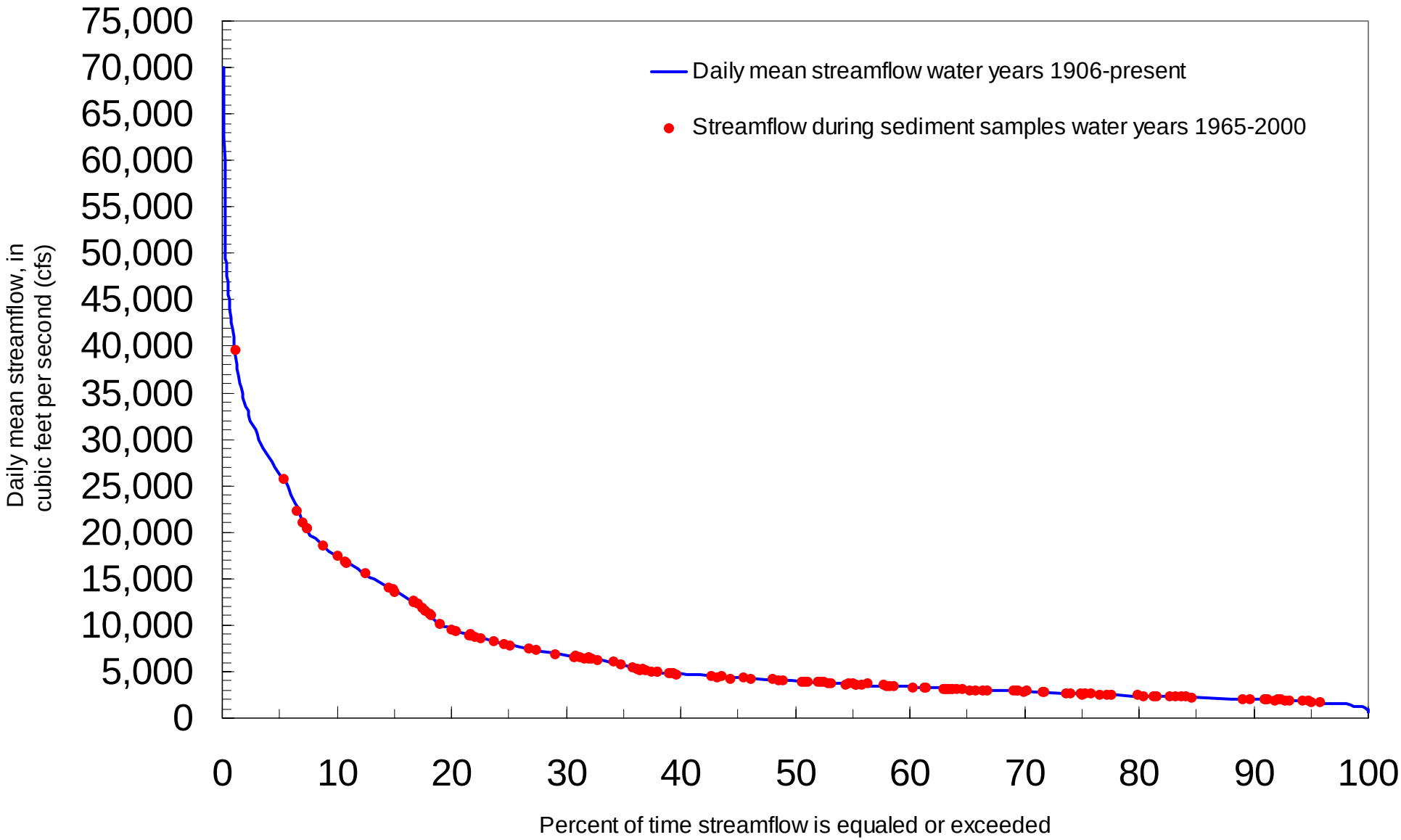
Flow-duration curve and refined sample distribution for silt and clay fraction of suspended-sediment load at station 09261000, Green River near Jensen, Utah.



Flow-duration curve and refined sample distribution for total suspended-sediment load at station 09315000, Green River at Green River, Utah.



Flow-duration curve and refined sample distribution for sand fraction of suspended-sediment load at station 09315000, Green River at Green River, Utah.



Flow-duration curve and refined sample distribution for silt and clay fraction of suspended-sediment load at station 09315000, Green River at Green River, Utah.